GEOHYDROLOGY, WATER AVAILABILITY, AND WATER QUALITY OF JEFFERSON COUNTY, WEST VIRGINIA, WITH EMPHASIS ON THE CARBONATE AREA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 90-4118

Prepared in cooperation with the
JEFFERSON COUNTY COMMISSION
and the
WEST VIRGINIA DEPARTMENT OF NATURAL RESOURCES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To Obtain
inch (in.)	25.4	millimeter (mm)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallons per minute per foot [(gal/min)/ft]	0.01923	liters per second per meter [(L/s)/m]
gallons per day per square mile [(gal/d)/mi^2]	3.785	liters per day per square kilometer [(L/d)/km^2]
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 -- a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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by M. D. Kozar, W. A. Hobba, Jr., and J. A. Macy

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1991

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MANUEL LUJAN, JR., Secretary

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Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey, WRD
603 Morris Street
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ABSTRACT

Jefferson County, an area of approximately 212 square miles, is a rapidly growing area in the eastern panhandle of West Virginia. Approximately 86 percent of the county is underlain by folded and faulted carbonate rocks. The remaining 14 percent of the county is underlain by folded shale and metamorphic rocks. Spring discharge data indicate that the Chambersburg Limestone of the Trenton Group, the Beekmantown Group, and the Conococheague Formation have yields of more than 1,300,000, 290,000, and 175,000 gallons per day per square mile, respectively. These carbonate units also have the greatest densities of mapped sinkholes per square mile of outcrop. Results from three dye-tracer tests indicate that flow rates in the carbonate aquifer range from 70 to 840 feet per day parallel to strike, and 30 to 235 feet per day perpendicular to strike. Areal aquifer analyses indicate that the horizontal hydraulic conductivity parallel to strike is four to nine times greater than it is perpendicular to strike. Based on streamflows and water-table gradients, estimates of transmissivity parallel to strike were 3,900 and 4,100 feet squared per day, and 800 and 1,100 feet squared per day perpendicular to strike.

Water samples from 62 wells and 8 springs were analyzed for most common dissolved constituents and bacteria in July 1988. Nitrate concentrations ranged from less than 0.1 to 63 mg/L (milligrams per liter); the median was 5.8 mg/L. Chloride concentrations ranged from 1.3 to 270 mg/L; the median was 12 mg/L. There was no significant difference in the concentrations of nitrate or chloride when comparing 1974 to 1988 data. Manganese concentrations ranged from less than 1.0 to 680 μg/L (micrograms per liter); the median was 1.0 μg/L. About 53 percent of the samples contained fecal coliform bacteria, and the median count was 1 colony per 100 milliliters. About 70 percent of the samples contained fecal streptococcal bacteria; the median count was 6 colonies per 100 milliliters. The ratios of fecal coliform to fecal streptococci indicate that most of the contamination is derived from animal wastes. Of the 30 wells and springs sampled and analyzed for 22 pesticides in the organochlorine and organophosphate classes, only 9 samples contained detectable concentrations of pesticides (DDE, endrin, dieldrin, and heptachlor). Eight of the nine samples were from wells or springs in or near orchards. Three wells, two springs, and two streams were sampled quarterly. There were no significant increases or decreases in common dissolved constituents, but alkalinity was generally highest during the spring of 1989. Quarterly samples at two sites on the same small stream show that average annual concentrations of 18 of 25 common constituents increased in the downstream direction.

INTRODUCTION

Jefferson County is primarily an agricultural area in eastern West Virginia (fig. 1), approximately 50 mi (miles) northwest of Washington, D.C. Many people who work in the Washington, D.C. area are relocating to this predominantly rural county. From 1970 through 1980, the population in the county increased 42 percent (Jefferson County Planning Commission, 1986, p. II-2). As the population increases, the demand for potable and dependable water supplies increases.

Most of the county is underlain by carbonate rocks, most of which have undergone some degree of karstification. Ground-water recharge in the karst areas occurs directly through sinkholes, caves, streams, and by direct infiltration of precipitation. Ground-water velocities can be rapid, and contaminants entering the ground-water-flow system can affect a large part of the aquifer in a short period of time.

Because of the increasing need for potable water supplies and concern for the vulnerability of the existing water supply to contaminants, the U.S. Geological Survey, in cooperation with the Jefferson County Commission and the West Virginia Department of Natural Resources, conducted a countywide investigation of the ground-water resources.

Purpose and Scope

This report presents the results of a study to (1) delineate the ground-water-flow system in the carbonate aquifer in Jefferson County, (2) describe the geohydrologic framework within the county, (3) assess the overall ground-water quality, and (4) identify areas where changes in water quality have occurred.

Most of the populated areas, farms, orchards, industrial areas, and many of the new developments are underlain by carbonate rocks. Therefore, most of the data-collection activities were concentrated in the carbonate areas.

Description of the Study Area

Jefferson County, an area of approximately 212 mi^2 (square miles), is in the eastern panhandle of West Virginia. It is the easternmost county in the State. The county is bounded on the northwest by Opequon Creek, on the northeast by the Potomac River, on the southeast by the Blue Ridge Mountains, and on the southwest by Virginia (fig. 1).

Most of the county is in the Shenandoah Valley of the Valley and Ridge physiographic province (fig. 1). The Shenandoah Valley has a subdued and gently rolling topography. In the valley part of the county, elevations range from about 400 to 600 ft (feet) above sea level (Beiber, 1961). The southeastern edge of the county is in the Blue Ridge physiographic province. In this part of the county, elevations range from about 1,100 to 1,700 ft above sea level (Beiber, 1961).

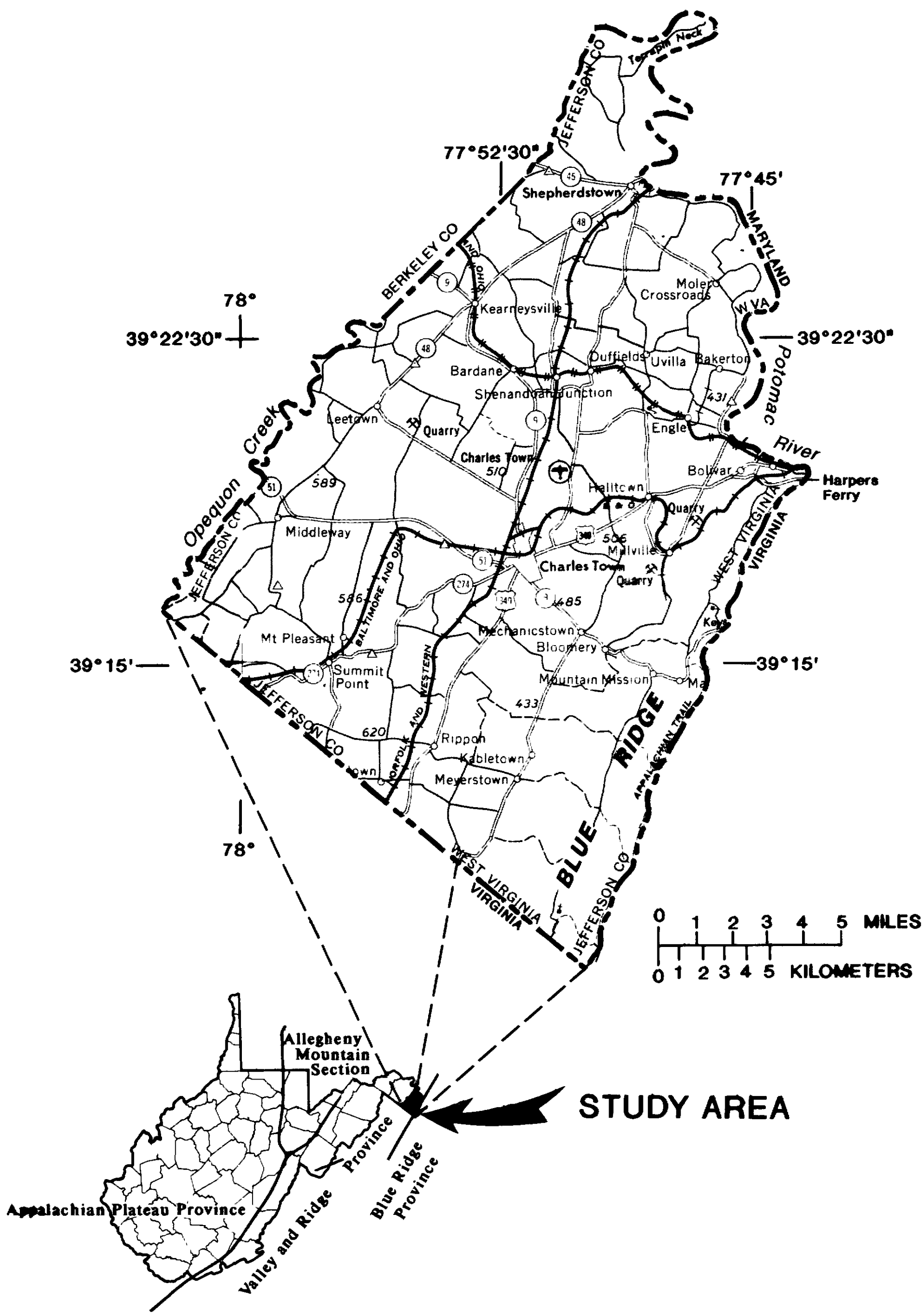

Figure 1.-- Location of study area and physiographic provinces in West Virginia.

Annual precipitation in the county is approximately 39 in/yr (inches per year). Of this amount, an estimated 28 to 30 in. (inches) is lost to evapotranspiration (Hobba and others, 1972). About 9.5 in. [roughly 80 Mgal/d (million gallons per day)] recharge the ground-water system in the carbonate areas, and ultimately discharge to streams.

Acknowledgments

The authors thank Mr. Scott Shipe for his assistance in locating springs and wells in the study area and in collecting water samples; Mr. Kevin Lilly, West Virginia Department of Natural Resources, for his assistance in collecting the data from the dye-tracer tests; the Jefferson County Commission for providing the fluorometric analyses; and the residents of Jefferson County for allowing us to sample their wells, and for providing us with well-construction information.

GEOHYDROLOGY

The main natural factors affecting ground-water recharge and the flow systems in Jefferson County are geology and precipitation. Because average annual rainfall is nearly constant over the county (Hobba and others, 1972, p. 11), geology has the dominant effect on the hydrology. Most of the county is underlain by carbonate rocks (limestones and dolomites). However, the Blue Ridge Mountain area is underlain by metamorphosed shales and sandstones, and the area near Opequon Creek is underlain by shale. Each of these areas has different hydrologic properties.

Geohydrologic Framework[1]

The geology in Jefferson County is complex. All of the geologic units in the county are faulted and folded, the axes of the folds trend northeast-southwest (figs. 2 and 3). This has produced outcrop bands with the same northeast-southwest trend (fig. 3). In general, the rocks strike northeast, dip southeast and northwest, and decrease in age from east to west.

A Precambrian metamorphic greenstone, the Catoctin Formation, crops out in a small area in the southeast part of the county (fig. 2). The remainder of the county is underlain by Cambrian metamorphic and sedimentary rocks and Ordovician sedimentary rocks (fig. 2).

The Cambrian rocks consist of the metamorphic sandstones and shales of the Weverton-Loudon, Harpers, and Antietam Formations; the Tomstown Dolomite; and the limestones of the Waynesboro, Elbrook, and Conococheague Formations (fig. 2). The limestones crop out in a wide band along the western side of the Shenandoah River (fig. 2).

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[1] The stratigraphic nomenclature used in this report is that of the West Virginia Geological and Economic Survey (Cardwell and others, 1968, 1986) and may not necessarily follow usage of the U.S. Geological Survey.

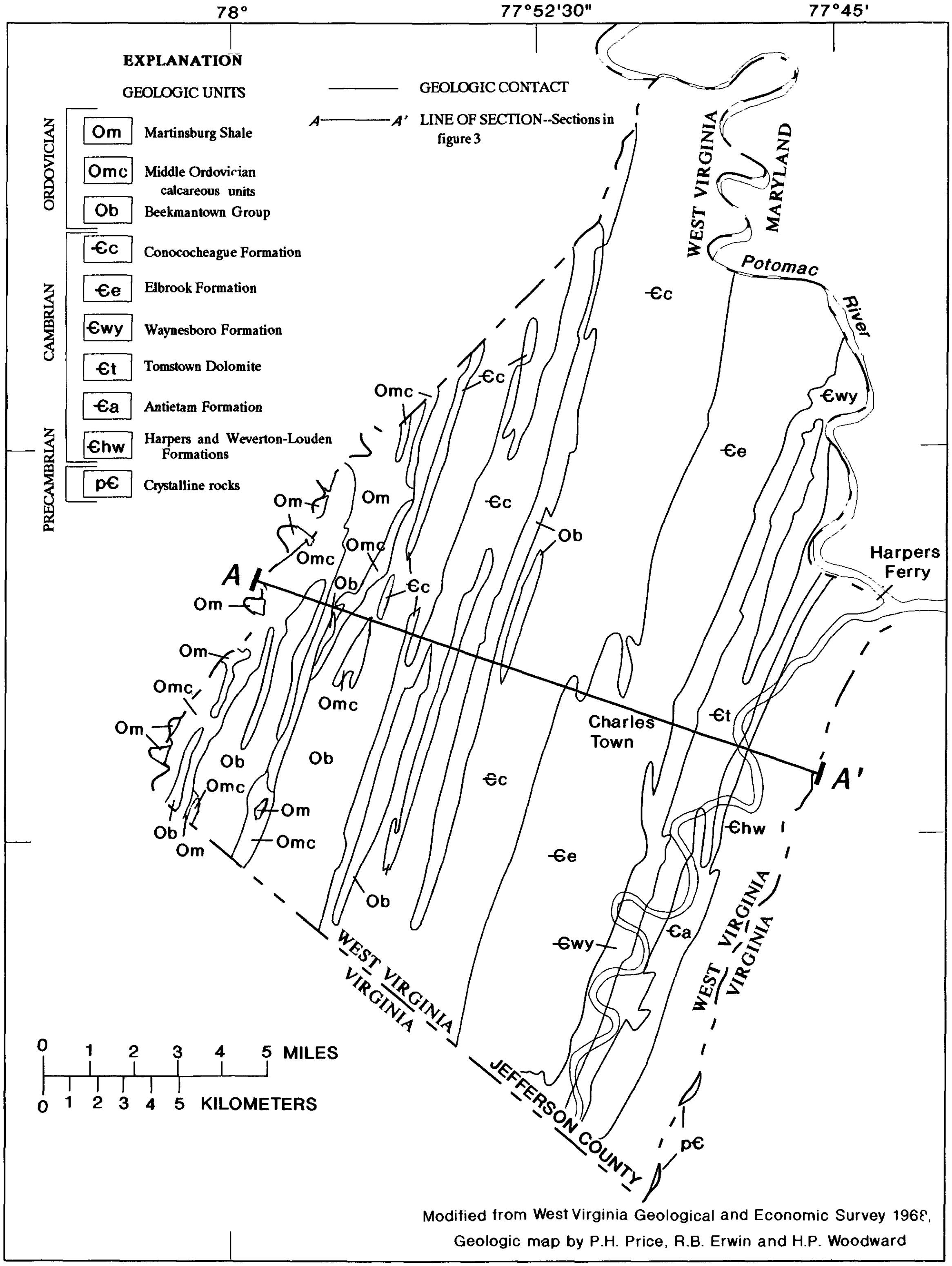


Figure 2.-- Generalized geology of Jefferson County, West Virginia.

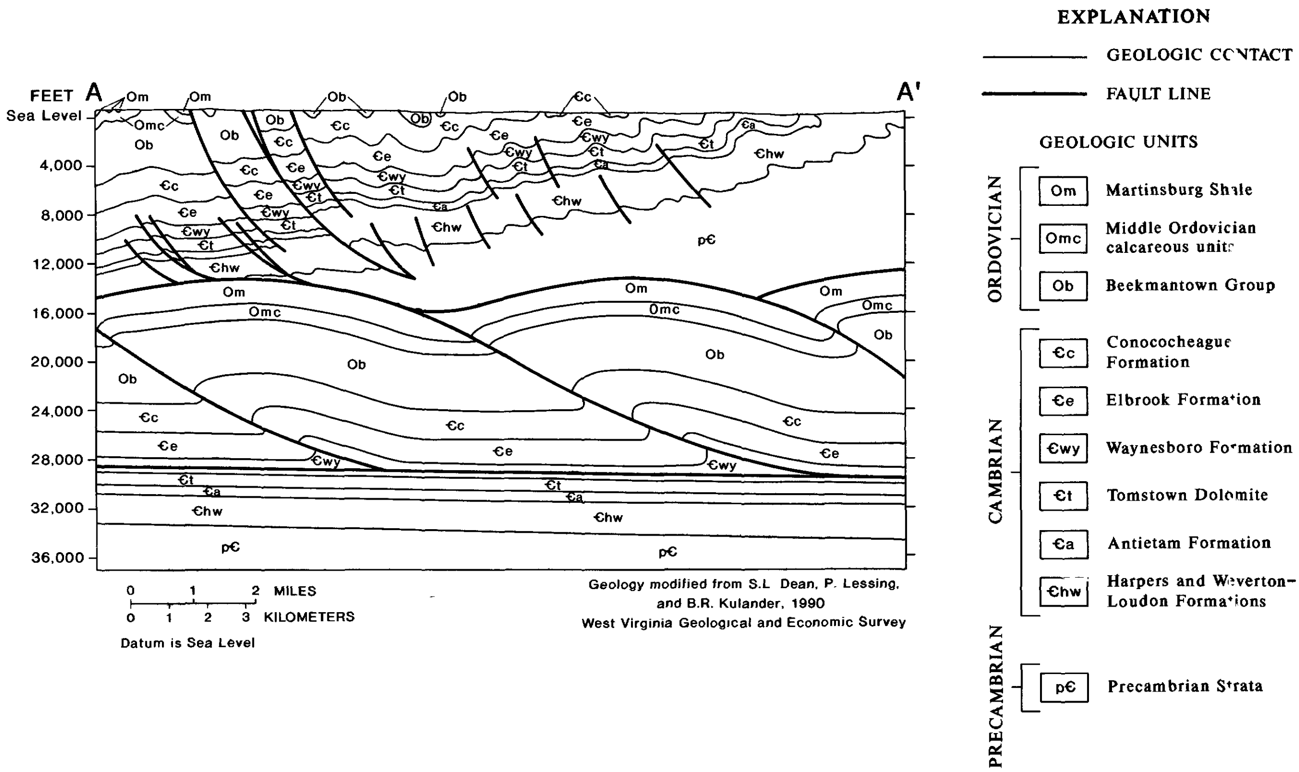


Figure 3.-- Geologic sections through Jefferson County, West Virginia.

The Ordovician rocks include the limestones of the Beekmantown Group, and the Black River, St. Paul, and Trenton Groups (collectively referred to as the "Middle Ordovician" calcareous units in fig. 3); and the shales of the Martinsburg Formation (fig. 2). The Martinsburg Formation, the youngest formation in the county, crops out as a band along Opequon Creek at the northwestern boundary of Jefferson County (fig. 2).

Based on lithology, the county can be divided into carbonate and noncarbonate areas (fig. 4). Each area has its own separate aquifer system. These aquifers, hereafter referred to as the "carbonate and noncarbonate aquifers," have their own distinct characteristics.

The carbonate aquifer (fig. 4) is composed of the Tomstown Dolomite; the limestones of the Waynesboro, Elbrook, and Conococheague Formations; and the Beekmantown, St. Paul, Black River, and Trenton Groups. It is bounded by the Shenandoah River to the east and Opequon Creek to the west, and underlies the central 86 percent of the county (fig. 4). Although the soils overlying the aquifer are only moderately permeable (Hatfield and Warner, 1973), surface runoff is negligible. The aquifer is recharged primarily from precipitation. Water percolating into and through the carbonate rocks dissolves rock materials and enlarges minute fractures in the rock. In Jefferson County, dissolution has produced a karst system containing caves, springs, disappearing and underground streams, and a land surface that is, in places, dotted with sinkholes (fig. 5).

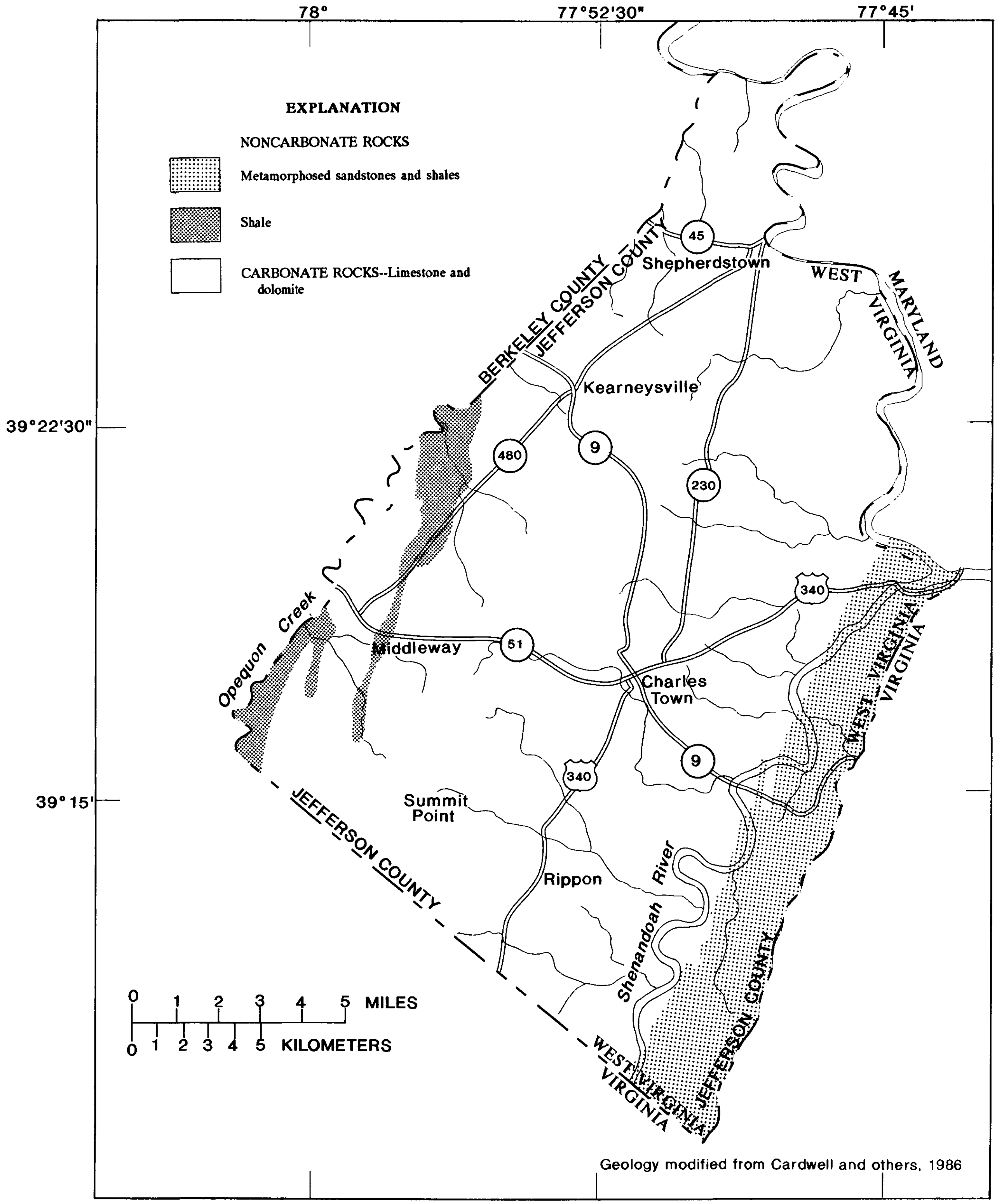


Figure 4.-- Location of carbonate and noncarbonate areas in Jefferson County, West Virginia.

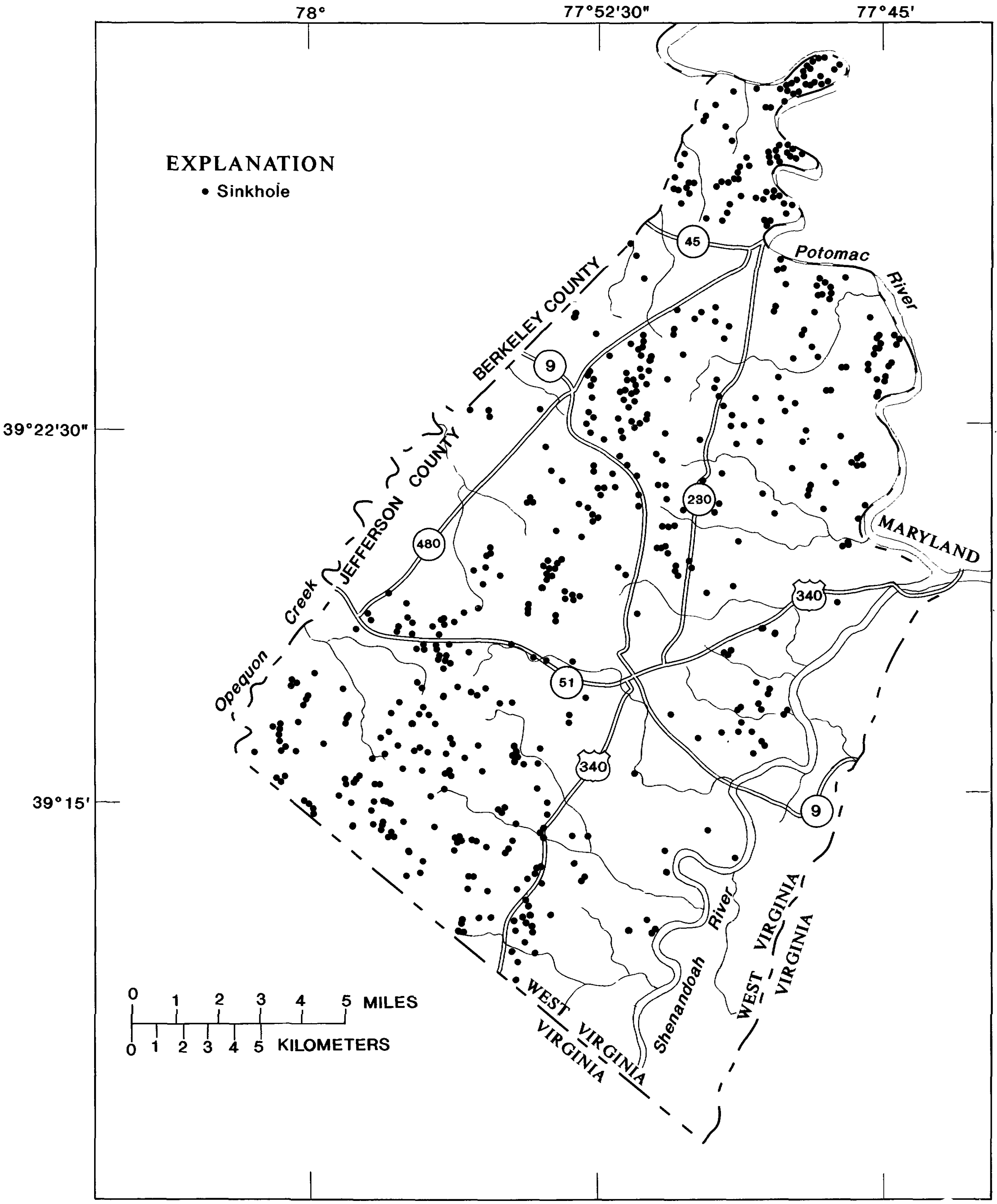


Figure 5.-- Sinkholes mapped in Jefferson County, West Virginia.

Sinkholes were mapped by a ground-reconnaissance survey. The Chambersburg Limestone of the Trenton Group, the Beekmantown Group, and the Conococheague Formation have the greatest density of mapped sinkholes per square mile of outcrop (fig. 5). The density ranges from 3.5 sinkholes per square mile in the Chambersburg Limestone of the Trenton Group to 5.0 sinkholes per square mile in the Beekmantown Group.

The noncarbonate aquifers occur along the eastern and western boundaries of the county (fig. 4). In the eastern part of the county, the aquifer consists primarily of metamorphosed sandstones and shales of the Harpers and Antietam Formations (fig. 2). It is bounded by the Blue Ridge Mountains to the east and the Shenandoah River to the west. The soils overlying the aquifer are permeable, but surface runoff from precipitation can be significant, especially on the Blue Ridge Mountains (Hatfield and Warner, 1973). The aquifer is recharged primarily from precipitation. Although the aquifer tends to yield less than 5 gal/min (gallons per minute) to wells, the yields generally are adequate for most domestic uses. In the western part of the county, the noncarbonate aquifer is composed of the Martinsburg Shale (fig. 2). The aquifer is generally bounded to the west by Opequon Creek and to the east by the carbonate aquifer. Although the soil overlying the shale is less permeable than the soil overlying the metamorphic rocks in the eastern part of the county (Hatfield and Warner, 1973), it does permit the downward percolation of water into the shale. Yields from this aquifer also are low, but they generally are adequate for most domestic needs.

Ground-Water Levels

Ground-water levels in the carbonate and noncarbonate aquifers fluctuate in response to recharge to or discharge from the aquifers. The range in annual water-level fluctuations generally is greater in recharge areas than it is in discharge areas. Infiltration of precipitation and surface water are the main sources of recharge to the carbonate aquifers. As the water moves through the aquifer to discharge at streams, springs, or wells, it is temporarily stored in fractures and cavernous openings.

The depth to water varies with geologic and topographic setting. For example, the depth to water in eight wells in valley areas underlain by carbonate rocks ranges from 5 to 105 ft and averages 30 ft. The depth to water in 67 wells in hillside and hilltop areas underlain by carbonate rocks ranges from 9 to 224 ft and averages 70 ft. This average depth is more than twice the average depth to water beneath the valley areas.

The depth to water in 13 wells in hillside and hilltop areas underlain by noncarbonate metamorphic rocks of the Blue Ridge Mountains ranges from 25 to 106 ft and averages 60 ft. In this area of high relief, the average depth to water is less than it is in the low-relief hilltops and hillsides of the carbonate areas. Even though the hydraulic gradients driving ground-water flow is generally steeper in the metamorphic rocks, the hydraulic conductivity is lower than in the carbonate rocks. As a result, water moves more slowly and water levels remain at higher levels in the noncarbonate metamorphic rocks than in the carbonate rocks (Hobba and others, 1972).

The depth to water in eight wells in the hillside and hilltop areas underlain by the noncarbonate shales of the Martinsburg Formation ranges from 5 to 21 ft and averages about 15 ft. The average depth to water is less here than in either the carbonate or noncarbonate metamorphic rocks because of the low permeability and the low topographic relief (Hobba and others, 1972).

Long-term records of ground-water levels can be used to describe ground-water conditions of an area with respect to drought, land use, and ground-water storage (Hobba and others, p. 67-69, 1972). The hydrograph of water levels from October 1969 to June 1989 in observation well 20-5-7 at Martinsburg, Berkeley County, West Virginia (fig. 1), shows annual fluctuations and long-term upward or downward trends (fig. 6).

When the 1974 potentiometric map (Hobba, 1981) is superimposed on a geologic map (fig. 7), ground-water mounds (closed contours) are apparent in the Conococheague Formation. The potentiometric contours in the adjacent Beekmantown Group are broadly spaced and "U" shaped. Thus, the contours indicate that there are zones of less permeable rock in the Conococheague Formation, and that, in general, the Beekmantown Group is more permeable than the Conococheague Formation. The beds of shaly limestone, shales, and sandy limestones in the Conococheague Formation (Grimsley, 1916, p. 287) tend to be less permeable than limestone and may cause the mounds in the Conococheague Formation.

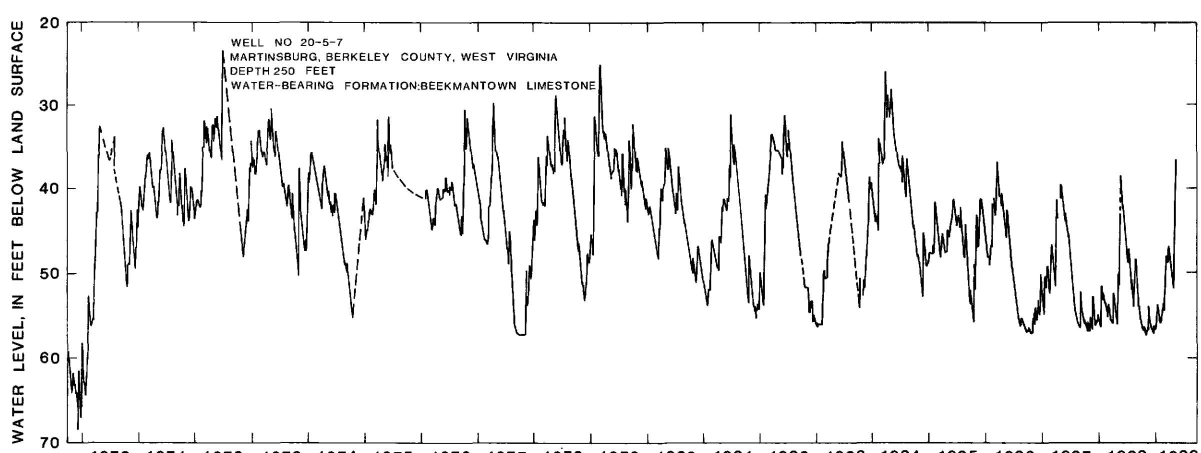


Figure 6.-- Noon daily water levels at well 20-5-7 at Martinsburg, West Virginia, showing seasonal fluctuations and approximate water levels at time water-quality samples were collected.

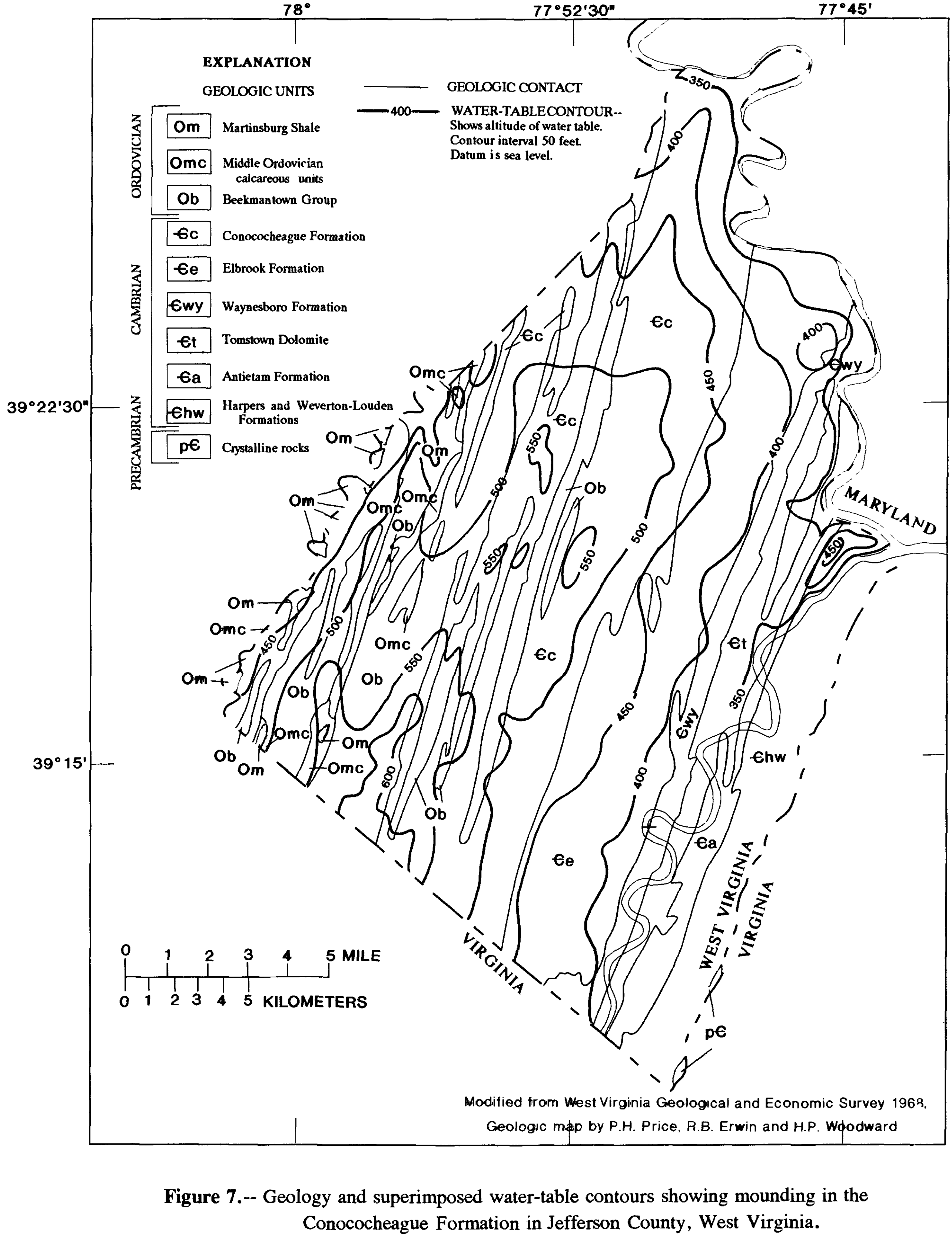


Figure 7.-- Geology and superimposed water-table contours showing mounding in the Conococheague Formation in Jefferson County, West Virginia.

Ground-Water Flow

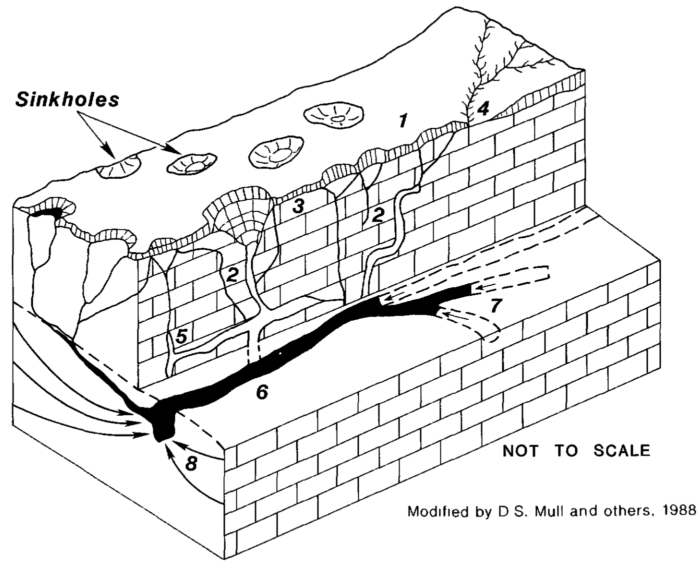
In Jefferson County, there appear to be two distinctly different types of flow systems—diffuse and conduit (fig. 8). In diffuse flow systems, ground water moves along bedding planes, faults, and joints that have not been significantly enlarged by dissolution. Large interconnected conduits have not developed (fig. 8). Most ground-water flow is laminar, and velocities tend to be slow. Ground water discharges from the aquifer at small springs and seeps (Mull and others, 1988). Diffuse flow occurs in both the carbonate and noncarbonate aquifers in Jefferson County.

A conduit flow system is dominated by solutionally enlarged and interconnected pipelike conduits or caverns (fig. 8). The conduits can form an intricate drainage system that in many ways resembles surface-water drainage patterns. Ground-water flow can be turbulent, and velocities can be rapid. In conduit flow systems, ground water can move rapidly even when there is little hydraulic gradient in the dominant direction of flow (Mull and others, 1988). Ground water commonly discharges at large springs (flows greater than 100 gal/min) along the margins of streams or it may form the headwaters of small streams. Conduit flow occurs only in the carbonate aquifers of the county.

Five qualitative dye-tracer tests (appendix A) were done in Jefferson County (fig. 9) to provide information about ground-water movement near the most populated parts of the county, and to provide information for a broad area of the carbonate aquifer. Several industries in the western part of the county use ground water from the carbonate aquifer. In order to insure that the dye would not contaminate their supplies, no dye-tracer tests were conducted in that part of the county.

The results of the two dye-tracer tests that used fluorescein dye were deemed inconclusive because of high background fluorescence. However, the results of the three dye-tracer tests (appendix A) that used Rhodamine WT support the premise of both diffuse and conduit flow systems in the carbonate aquifer. In these three tests, the dye generally moved normal to the strike of the rocks (perpendicular to the water-table contours) and parallel to the strike of the rocks (nearly parallel to the water-table contours) (fig. 9). Ground-water movement normal to the strike of the rocks was expected because of the larger hydraulic gradients in this direction, but little ground-water movement was expected parallel to strike, because the hydraulic gradients in this direction were much smaller. However, the dye-tracer tests (appendix A) indicate that flow along bedding planes, faults, joints, and fractures, parallel to the strike of the rock (northeast-southwest) typically was more rapid than flow along joints and fractures perpendicular to the bedding planes.

The dye injected near Shenandoah Junction, West Virginia (appendix A), was detected within 2 weeks in a spring-fed stream more than 4 miles away (fig. A-4, appendix A). A fault near the recovery site has been mapped to within 2 miles of the injection point. A hypothetical straight-line extension of this fault would bring it very close to the injection site. Dissolution along the fault could have created a conduit between the injection and recovery sites, which would explain the rapid movement of the dye.



EXPLANATION

1. DIFFUSE FLOW THROUGH SOIL, RESIDUUM, OR UNCONSOLIDATED SURFICIAL MATERIAL
2. FLOW THROUGH ENLARGED VERTICAL CONDUITS
3. DIFFUSE FLOW THROUGH JOINTS, FRACTURES, FAULTS, AND BEDDING PLANES
4. SURFACE STREAMS DRAINING INTO SINKHOLES
5. HORIZONTAL AND VERTICAL FLOW TO MASTER CONDUIT
6. WATER-FILLED MASTER CONDUIT
7. AIR-FILLED CONDUIT
8. FLOW LINES OF DIFFUSE GROUND-WATER FLOW

Figure 8.-- The components of ground-water flow in a cavernous carbonate aquifer.

Davies (1965) mapped 16 caves in Jefferson County, most of which are along bedding planes and joints parallel to the strike of the bedrock. The preferential development of caves along bedding planes and joints parallel to strike, the rapid movement of the dye parallel to strike, and the small hydraulic gradients parallel to strike suggest that conduits have developed along the bedding planes.

The dye-tracer test near Rippon, West Virginia, was begun on February 19, 1988 (appendix A). During the first 2.5 months of this test, cumulative precipitation for February, March, and April at the Kearneysville and Martinsburg National Oceanic and Atmospheric Administration precipitation stations was 3.48 and 2.96 in. below normal. However, precipitation for May was 4.87 (Kearneysville) and 6.10 (Martinsburg) in. above normal (National Oceanic and Atmospheric Administration, 1988). The heavy rains in May caused

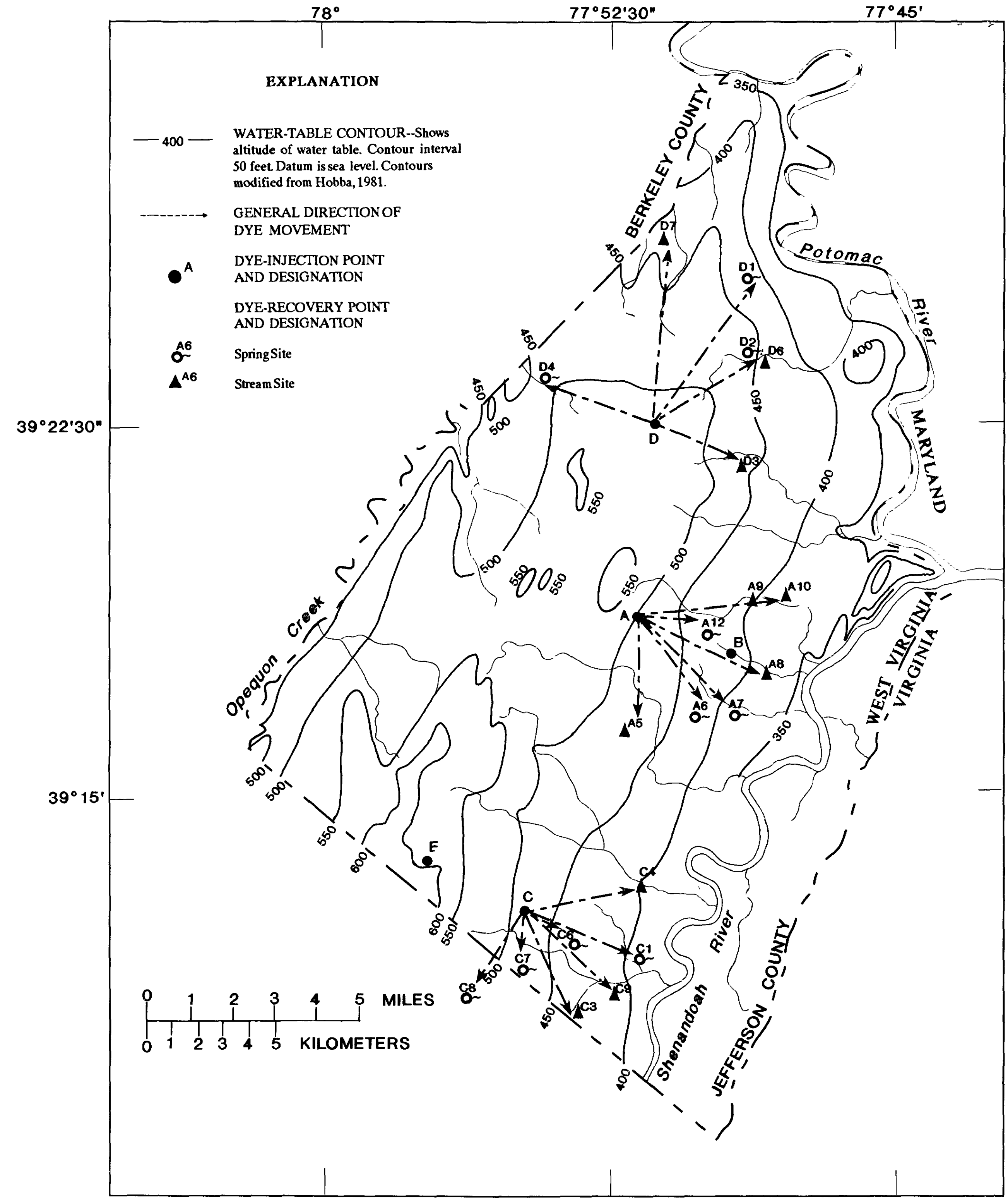


Figure 9.-- Water-table contours, dye-injection points, and generalized direction of dye movement in the ground water in Jefferson County, West Virginia.

small streams to flood and ground-water levels in the area to rise significantly. Water levels in an observation well at Rippon rose approximately 5 ft (fig. 10). During February, March, April, and in May before the heavy rains, no dye was detected at any of the expected resurgence points; however, dye was detected at seven sites within 5 weeks after the heavy rains (fig. A-3, appendix A). It is possible that recharge from the heavy rains caused localized mounding of the water table at various recharge points. This would have increased the hydraulic gradients and caused accelerated flow of the ground water and the dye through the system. Another possibility is that after the rise in water level, the water is able to move faster through the now saturated more permeable rocks closer to land surface.

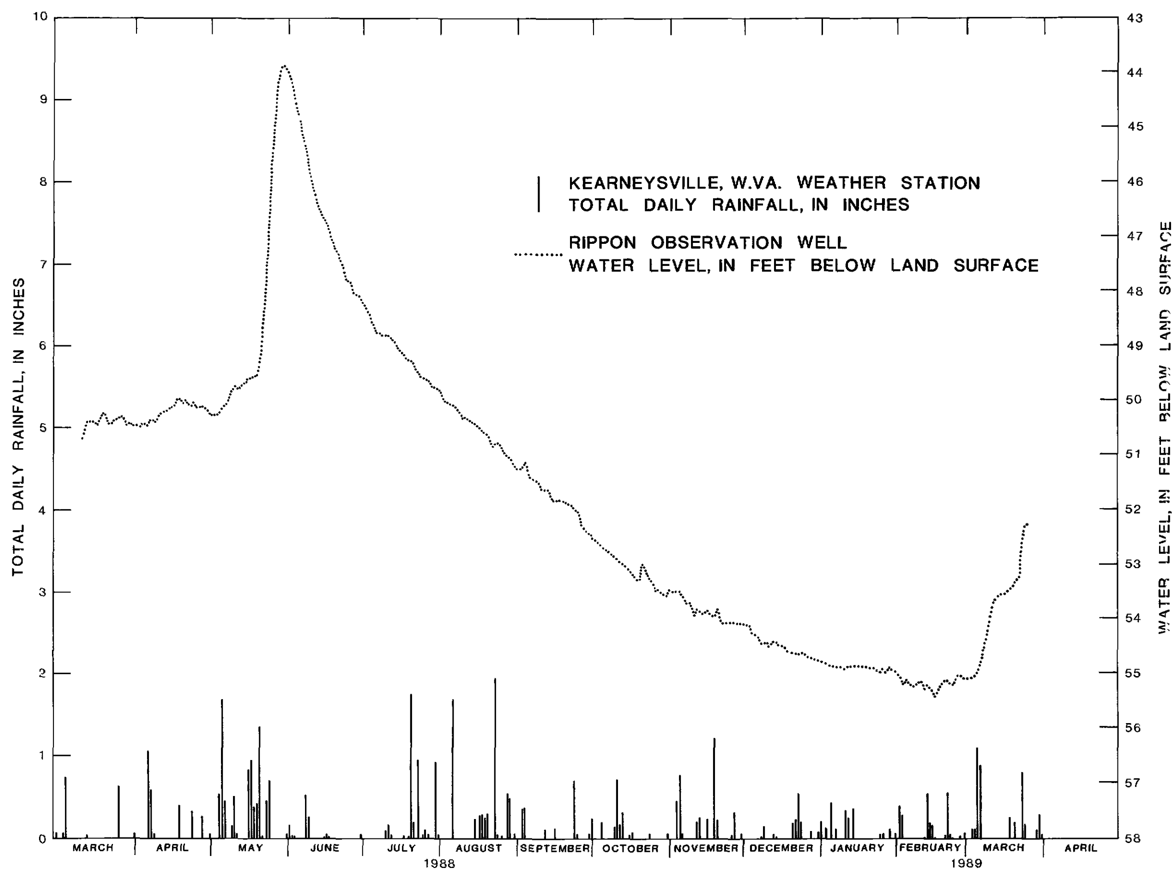


Figure 10.-- Water levels in the observation well at Rippon and the total daily rainfall at Kearneysville, West Virginia.

Hydraulic Characteristics of the Carbonate Aquifer

Hydraulic Conductivity

On the basis of three rhodamine WT dye-tracer tests, ground water moves along the strike of the rocks at 50 to 840 ft/d (feet per day) and perpendicular to strike at 30 to 235 ft/d. These tests indicate approximate rates of water movement, primarily in the Beekmantown Group, and the Conococheague and Elbrook Formations in the carbonate aquifer.

On the basis of these estimated velocities and estimated hydraulic gradients from a 1974 water-table map (Hobba, 1981), hydraulic conductivities[1/] parallel and perpendicular to the strike of the rocks were estimated using a form of Darcy's Law (Freeze and Cherry, 1979, p. 71)--

$$K = \frac{\bar{v}n}{i}$$

where
K = hydraulic conductivity, in ft/d;
$\bar{v}$ = average linear velocity, in ft/d;
n = porosity, in percent; and
i = the hydraulic gradient in ft/ft between injection and recovery sites.

Darcy's Law is a linear flow law that assumes laminar flow. When ground-water flow is not laminar (such as in some parts of limestone or karst aquifers), the flow law is not linear and Darcy's Law does not apply. However, Basmaci and Sendlein (1977, p. 205) applied Darcy's Law in a model analysis of karst aquifers knowing that some error is committed by assuming that flow is laminar through a fractured karst system. Estimates of hydraulic conductivity in Jefferson County were made knowing that the calculated values could be in error. However, it was assumed that the ratio of the calculated hydraulic conductivity parallel to strike to the calculated hydraulic conductivity perpendicular to strike would be the same as the ratio of the actual hydraulic conductivities parallel and perpendicular to strike.

Secondary permeability is a function of secondary porosity. Because secondary permeability in the study area is enhanced by solutioning parallel to strike, it was assumed that permeability parallel to strike was twice as great as that perpendicular to strike. Using the estimated ground-water velocities and hydraulic gradients, four estimates were made of the hydraulic conductivity parallel to strike (assumed porosity 0.06); seven estimates were made of the hydraulic conductivity perpendicular to strike (assumed porosity 0.03, Trainer and Watkins, 1975, p. 39). The hydraulic conductivities parallel to strike ranged from 2,900 to 15,000 ft/d.

[1/] In this report, unless stated differently, "hydraulic conductivity" refers to hydraulic conductivity in a horizontal direction.

The values perpendicular to strike ranged from 200 to 2,000 ft/d. The median hydraulic conductivity parallel to strike was 5,800 ft/d or 5 times the median hydraulic conductivity of the rock perpendicular to strike (1,260 ft/d). If the porosity is assumed to be 0.06 throughout the rock, the median hydraulic conductivity parallel to strike is still about 2.5 times greater than the hydraulic conductivity perpendicular to strike. These estimated hydraulic conductivities fall within the range of values for hydraulic conductivities in cavernous carbonate rocks—100 to 10,000 ft/d (Heath, 1983, p. 13).

That the hydraulic conductivity is greater parallel to strike (or to the northeast) is further substantiated by the fact that--

1. Most of the caves mapped or described by Davies (1965, p. 146-155) in Jefferson County trend to the north or northeast along the strike of the rocks.
2. Some of the sinkholes that were mapped during this study appear to have developed along lines that trend to the northeast (fig. 5).
3. Most of the observed solution cavities in outcrops and limestone quarries tend to parallel bedding planes.
4. Most of the mapped faults in Jefferson County trend to the northeast (Hobba, 1981), which probably increases the permeability in this direction.
5. The most rapid rates of dye movement in the ground water were to the northeast.
6. An aquifer test at the National Fisheries Center at Leetown (Jones and Deike, 1981, p. 44), West Virginia, indicates that hydraulic conductivity is greater parallel to strike than it is perpendicular to strike.

Transmissivity and Recharge

Transmissivity and ground-water-recharge rate can be estimated for a relatively large volume of rock from measurements of streams at base flow and the gradient of the water table (Stallman, in Ferris and others, 1962, p. 130-132). The method assumes that (1) the aquifer is bounded on two sides by streams of infinite length that fully penetrate the aquifer, (2) the aquifer is homogenous and isotropic, and (3) recharge is at a constant rate of accretion with respect to time and space.

Trainer and Watkins (1975, p. 31) state that ..."use of the gradient method is justified in the Appalachian Valley, despite the strong directional properties of the rock." Therefore, the gradient method was used to calculate transmissivity and ground-water recharge for some reaches of streams in Jefferson County even though all the assumptions were not completely satisfied. The assumption of complete penetration is partly fulfilled, because, in most parts of the county underlain by carbonate rocks, the near-surface zone of relatively permeable rock probably does not extend far below stream level in most places. The carbonate rocks are not isotropic, but if only the directional flow parallel or perpendicular to strike is considered, the aquifer can be considered isotropic. If a large enough segment of the aquifer is considered, the aquifer can be considered homogeneous (Basmaci and Sendlein, 1977, p. 205).

The areal extent of the contributing area of each of the four sites investigated was approximately 6 miles squared. The water-table map for September 1974 (Hobba, 1981) was used to determine the hydraulic gradients to the streams. The mean flow used in the calculations was selected at a time when the water level at the Martinsburg observation well was the same as when the 1974 water-table map was prepared. The selected water level was about 6 ft lower than the mean annual water level (45.13 ft) for the past 30 years at the observation well; therefore, the computed values of recharge and transmissivity may be lower than if they were based on flows measured when ground-water levels were high.

Calculations were made using measured discharges over known reaches of three streams and the estimated slope of the water table (Hobba, 1981). The transects along which transmissivity was estimated based on water-table gradient and streamflow are shown in figure 11. North Fork Long Marsh Run and the uppermost reach of Bullskin Run (fig. 11, traces C-C′ and D-D′) cut across the strike of the rock. Thus, much of the ground water entering the streams is probably moving parallel to the strike of the rocks (fig. 2). Rocky Marsh Run and the reach of Bullskin Run that contains Head Spring Bullskin Run and White House Spring (fig. 11, traces E-E′ and F-F′) flow parallel to the strike of the rocks. Thus, much of the ground water entering these streams is probably moving perpendicular to the strike of the rock. Water-table contours for the study area support the flow directions theorized here.

For the areas around North Fork Long Marsh Run and the uppermost reach of Bullskin Run (fig. 11), the estimated transmissivities parallel to the strike of the rocks (table 1) are 3,900 and 4,100 ft^2/d (feet squared per day), respectively, and the estimated recharge rates are 11 and 7 in/yr, respectively. These rates of recharge seem reasonable in that Hobba and others (1972, p. 16) estimated from streamflow records that runoff in Jefferson County is 10 to 11 in/yr. Of this amount, it is estimated that 85 percent, or about 9 in/yr, is contributed by ground-water discharge (Hobba and others, 1972, p. 22 and Nutter, 1973, p. 13).

Table 1.--Estimates of recharge and transmissivity parallel to the strike of rocks, based on streamflow

[C-C′, trace of profile on figure 11]

Stream (and map profile trace)	Discharge (gallons per minute)	Calculated recharge (inches)	Calculated transmissivity (feet squared per day)	Approximate contributing area (square miles)	Geology	Remarks
North Fork Long Marsh Run (C-C′)	1,375	11.0	3,900	3.8	Elbrook-Conococheague	Channel normal to strike
Uppermost reach of Bullskin Run (D-D′)	1,400	7.1	4,100	6.0	Conococheague-Beekmantown	Do.

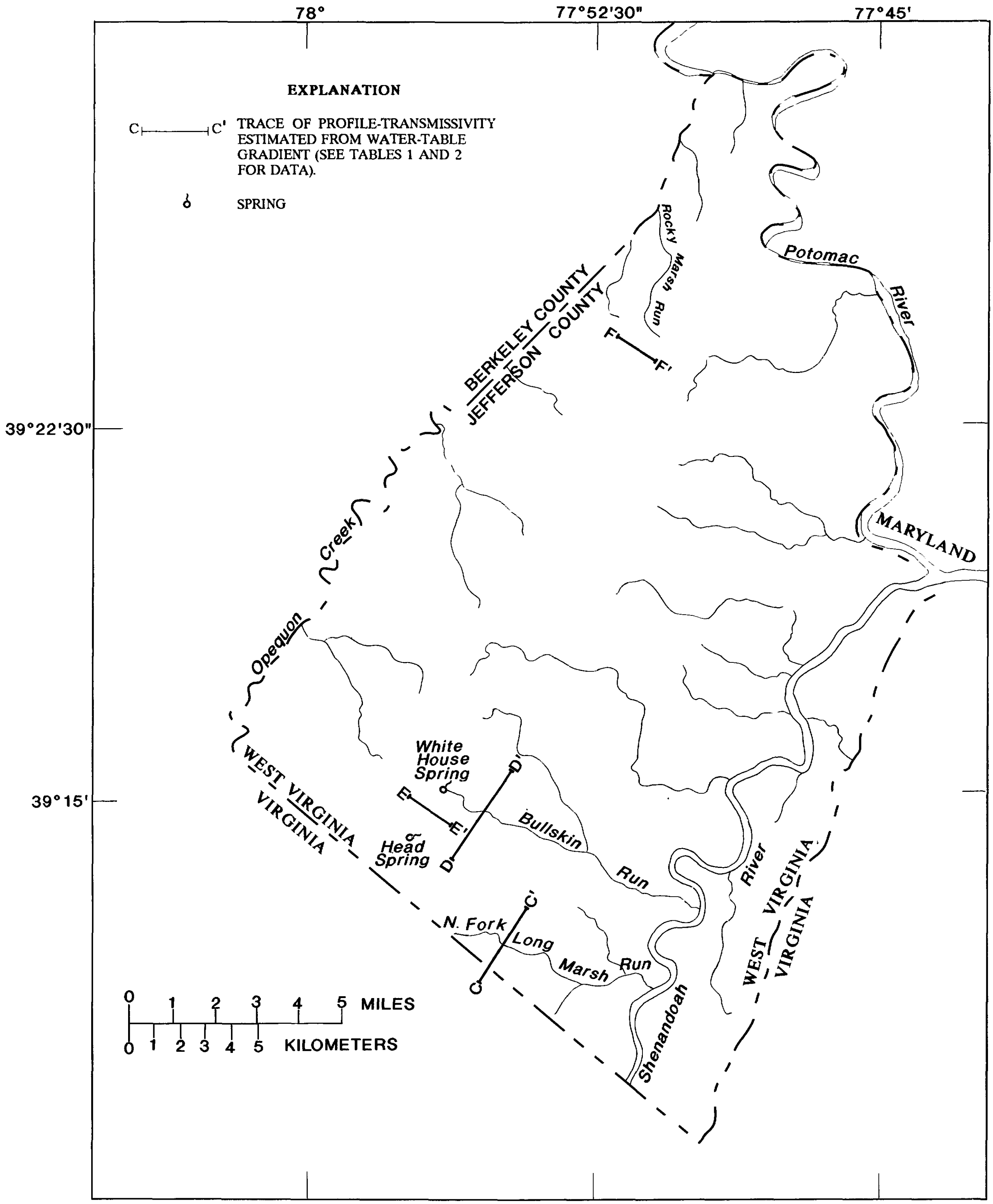


Figure 11.-- Location of North Fork Long Marsh Run, Bullskin Run, Rocky Marsh Run, Head Spring Bullskin Run, and White House Spring in Jefferson County, West Virginia.

For the areas around Rocky Marsh Run and the reach of Bullskin Run that contain Head Spring Bullskin Run and White House Spring (fig. 11), the estimated transmissivities perpendicular to the strike of the rocks (table 2) are 1,100 and 800 ft^2/d, respectively, and the estimated recharge rates are 20 and 17 in/yr, respectively. These estimated recharge rates are probably too high, because a part of the water entering the stream is actually water that is moving along the strike. Thus, there is more water per foot of channel than there should be. Use of this high recharge rate produces an overestimate of transmissivity. Recalculating the transmissivity on the basis of a probable rate of recharge of 10 in/yr, the transmissivities perpendicular to the strike of the rocks around Rocky Marsh Run and Bullskin Run (table 2) are 550 and 480 ft^2/d, respectively. Assuming that these values are correct, then the ratio of the transmissivity parallel to strike compared to the transmissivity perpendicular to strike is 1:7 or 1:8. These ratios support the conclusion that the dominant direction of ground-water flow is parallel to strike along bedding planes, faults, and fractures.

Trainer and Watkins (1975, p. 32) made similar areal computations of transmissivity and rates of recharge for various places throughout the Potomac River basin. For a site in northern Jefferson County, adjacent to the Potomac River, they estimated the transmissivity to be 5,170 ft^2/d (parallel to the strike of the rocks) and the recharge to be 10 in/yr. This transmissivity, which is primarily for the Conococheague and Elbrook Formations, is the highest transmissivity they estimated for the Potomac River basin. For one site east of Charles Town (adjacent to the Shenandoah River) and one site west of Charles Town (adjacent to Opequon Creek), they estimated transmissivities of 1,450 and 1,570 ft^2/d and recharge rates of 2.91 and 3.44 in/yr, respectively. These recharge rates are probably low, because the Shenandoah River and Opequon Creek drain carbonate and metamorphic rocks and shales. At these sites, the flow of ground water to these stream channels was primarily perpendicular to strike of the rocks. However, these streams also receive water from some tributaries that cut across the strike of the rocks, and therefore receive some ground water that flows parallel to strike. Even though the extra water contributed by these streams would tend to make the estimated transmissivities abnormally high, the transmissivity parallel to strike is still about 3.5 times greater than the values perpendicular to the strike.

Table 2.--Estimates of recharge and transmissivity normal to the strike of rocks, based on stream and spring flows

[E-E′, trace of profile on figure 11]

Stream	Flow (gallons per minute)	Recharge		Transmissivity		Approximate contributing area (square miles)	Geology	Remarks
		Calculated (inches)	Most probable (inches)	Calculated (feet squared per day)	Most probable (feet squared per day)			
Rocky Marsh Run tributary (F-F′)	624	20.2	10.0	1,100	550	9.9	Conococheague Beekmantown	Stream parallels fault and strike
Reach of Bullskin Run containing Head Spring and White House Spring (E-E′)	800	16.9	10.0	800	480	1.4	Conococheague Beekmantown	Channel parallel to strike

WATER AVAILABILITY AND USE

The amount of water available for use from the various aquifers can be estimated on the basis of the yields of springs and wells. The spring data are important to consider when evaluating the areal yield of aquifers. The well data are more important to consider when estimating water availability on a local scale.

Spring Yields

Analysis of spring-yield data (Erskine, 1948) indicates that the Chambersburg Limestone of the Trenton Group, the Beekmantown Group, and the Conococheague Formation are the most productive water-bearing units in the carbonate aquifer. These units underlie about 4, 19, and 32 percent of Jefferson County, respectively.

In July 1945, discharge measurements were made for about 40 large springs (over 100 gal/min) in the county (Erskine, 1948). At that time, ground-water levels were somewhat higher than the long-term normal for July (based on a correlation of current spring discharge measurements to the 30-year (1957-87) average July water level in the observation well at Martinsburg). Many of these same springs were measured again in October 1945, when ground-water levels were even higher because of 9.3 in. of rain that had fallen during September 1945. Calculations based on these spring-flow measurements show that discharges from the Beekmantown Group ranged from 290,000 to 485,000 (gal/d)/mi^2 (gallons per day per square mile); discharges from the Conococheague Formation ranged from 175,000 to 350,000 (gal/d)/mi^2; and discharges from the Chambersburg Limestone ranged from 1,300,000 to 1,500,000 (gal/d)/mi^2. Together, these three formations yield about 86 percent of the total flow to springs in the county.

Most of the streams draining the carbonate areas are fed by springs; therefore, spring flows and some stream flows would be expected to correlate with ground-water levels (Kelley, Gidley, Blair, and Wolfe, Inc., 1986, p. 41-46). As ground-water levels rise or fall, there generally is a corresponding increase or decrease, respectively, in the discharge of ground water to springs and streams. The relation of water levels in the observation wells at Rippon and Martinsburg to ground-water discharge at Aldridge Spring is shown in figure 12.

The flows of Aldridge Spring and the Head Spring of Bullskin Run vary with noon-daily water levels at the nearby observation well at Rippon (fig. 13). On the basis of the data point for May 20, 1989, both springs plot to the right of the line of best fit. This indicates that the yield of both springs is too high for the measured ground-water level and that the additional springflow is a result of overland runoff entering the rocks near the spring and then reemerging at the spring.

The flows of Bullskin Run at Kabletown and North Fork Long Marsh Run and the ground-water levels in the nearby Rippon observation well are shown in figure 14. The discharge of 56 ft^3/s (cubic feet per second) for Bullskin Run plots significantly off of the line of best fit. This flow, which occurred on May 19, 1988, is too great for the corresponding water level in the well, indicating that much of the flow is overland runoff from the heavy rains that occurred after May 15, 1988. A discharge measurement made on the same day at North Fork Long Marsh Run plots very close to the line of best fit (fig. 14), indicating that most of the water in the stream was being derived from ground water.

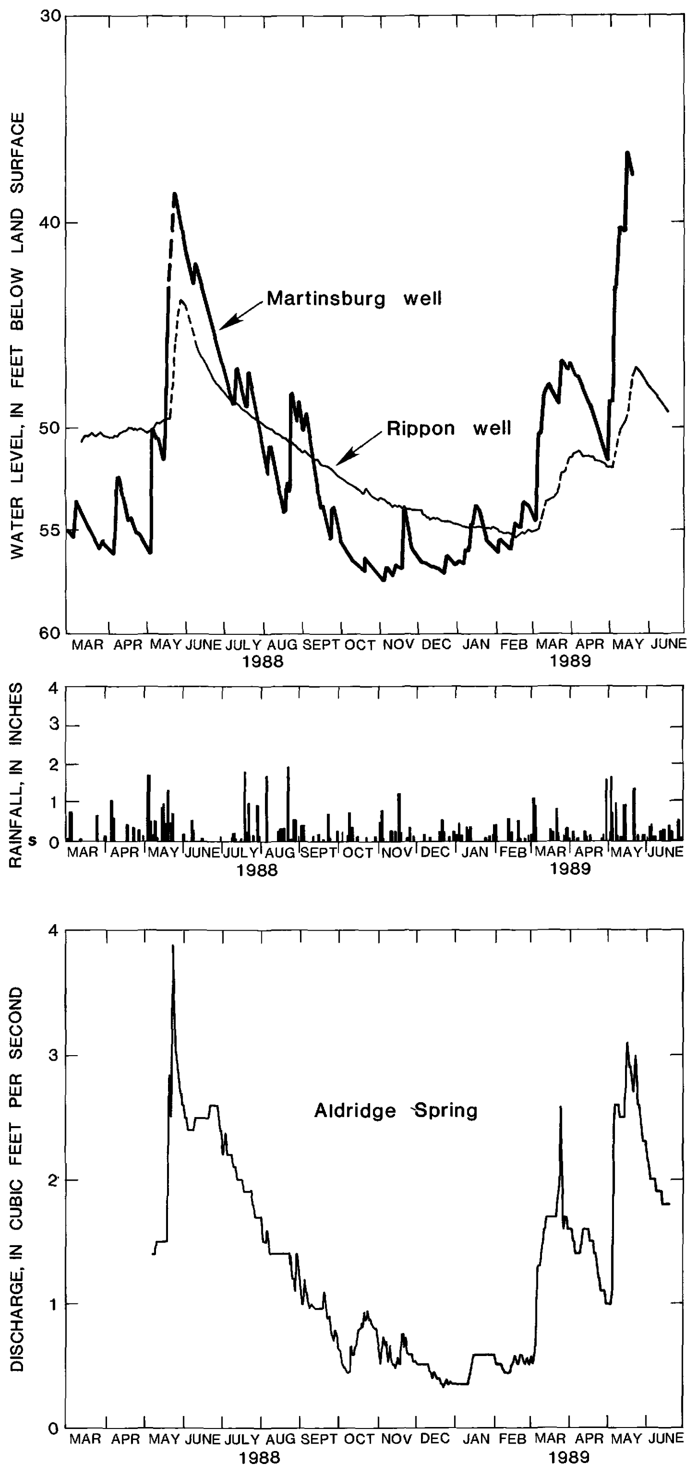


Figure 12.-- Water levels in observation wells at Rippon and Martinsburg, precipitation at Kearneysville, and mean daily discharge at Aldridge Spring, West Virginia, 1988-89.

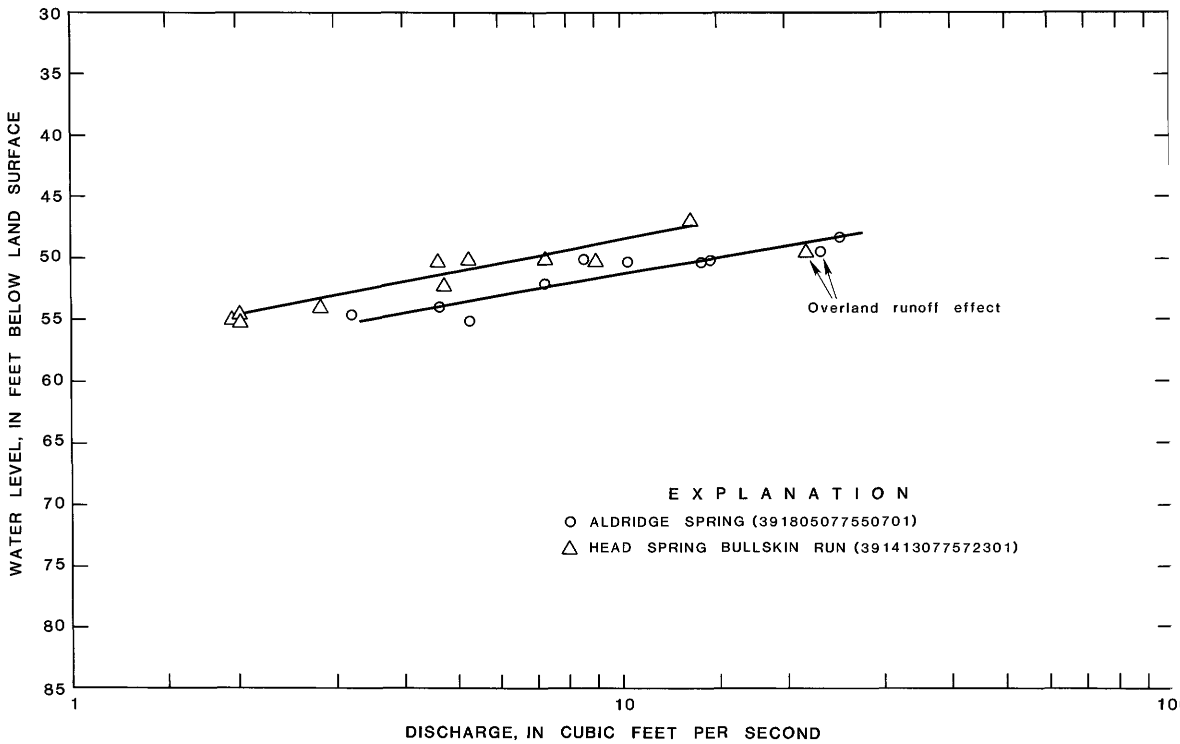


Figure 13.-- Water level in the observation well at Rippon as a function of flows of Aldridge Spring and Head Spring Bullskin Run.

The point labeled "pumpage upstream" on figure 14 shows how pumping from the stream (for irrigation in August 1988) upstream from the measuring point affects the correlation. For a ground-water level of 50.34 ft, streamflow should just exceed 3 ft^3/s; however, only 1.77 ft^3/s was measured. This indicates that the rate of pumping above the site was about 550 gal/min.

Well Yields

Beiber (1961, p. 20) showed that the zone of greatest yield per foot of drilled well in the carbonate rocks of Berkeley and Jefferson Counties was in the upper 50 ft of rock. The water discharging at many of the large springs is probably derived from this zone. However, this zone is commonly cased off in supply wells because of its nearness to land surface and its susceptibility to contamination.

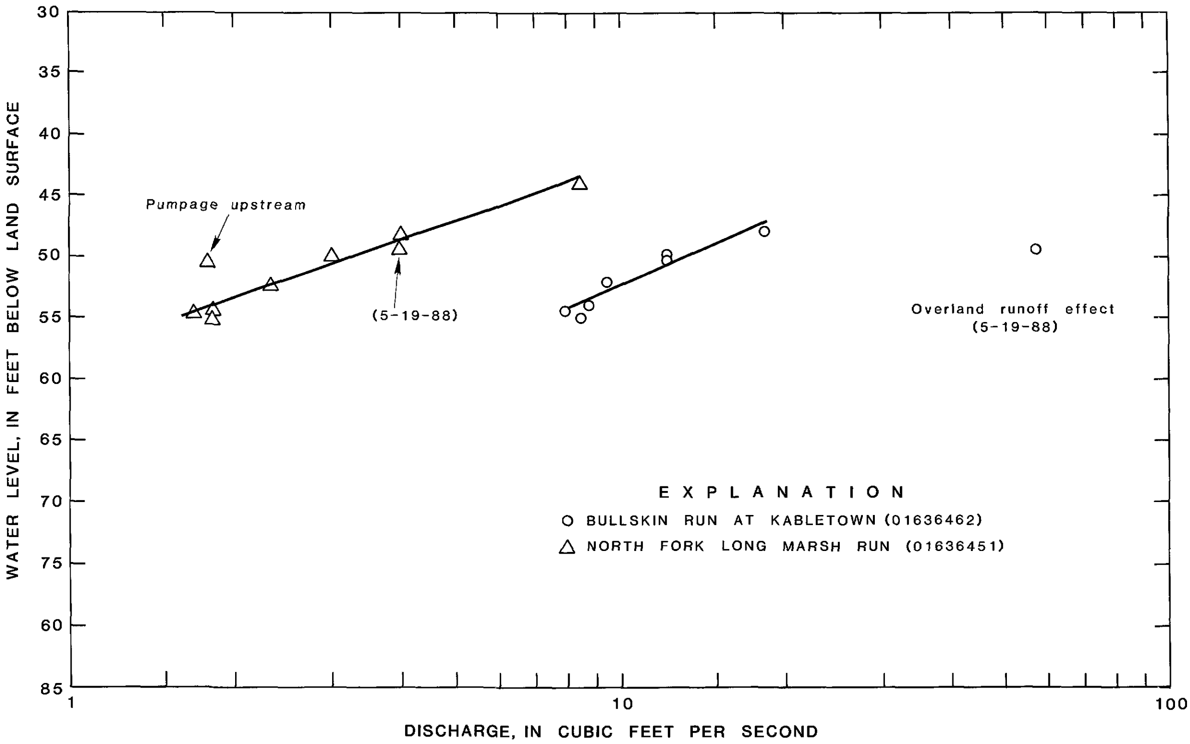


Figure 14.-- Water level in the observation well at Rippon as a function of flows of Bullskin Run at Kabletown, West Virginia, and North Fork Long Marsh Run.

The depth, yield, and specific capacity for well data in the U.S. Geological Survey Ground-Water Site Inventory (GWSI) computer data base are summarized in table 3. This table shows that the Beekmantown Group and the Conococheague Formation have the greatest number of wells less than 100 ft deep. The outcrops of the Beekmantown Group and the Conococheague Formation comprise about 50 percent of the land surface in Jefferson County. Yet 89 percent (8 of 9) of the wells yielding more than 101 gal/min tap these formations, and 75 percent (9 of 12) of the wells yielding 51 to 100 gal/min tap these formations. The table indicates that most of the wells which tap the Elbrook Formation yield 11 to 50 gal/min. The Chambersburg Limestone of the Trenton Group, the Beekmantown Group, the Conococheague and Elbrook Formations, contain all of the wells with specific capacities greater than 9.9 (gal/min)/ft (gallons per minute per foot of drawdown). Thus, these well data, in conjunction with the spring-yield data and the sinkhole data, all indicate that the Chambersburg Limestone of the Trenton Group, the Beekmantown Group, and the Conococheague and Elbrook Formations, are the most productive water-bearing units in the county.

An apparent inconsistency in the data is that 17 of 23 (74 percent) wells in the county that are deeper than 400 ft, tap the Beekmantown Group and the Conococheague Formations.

Table 3.--Summary of Ground-Water Site Inventory (GWSI) well data, by geologic unit

[-, no data available; ft, feet; gal/min, gallons per minute; (gal/min)/ft, gallons per minute per foot]

	Number of wells in each formation						
	Chambersburg Limestone	Beekmantown Group	Conococheague Formation	Elbrook Formation	Waynesboro Formation	Tomstown Dolomite	Number of wells
Well depth (ft)							
0-100	8	25	62	13	9	12	129
101-399	7	34	62	55	8	22	188
400-800	1	6	11	3	2	-	23
Well yield (gal/min)							
1- 10	5	7	19	3	6	4	44
11- 50	2	7	17	14	2	4	46
51-100	-	4	5	2	-	1	12
101-600	-	2	6	1	-	-	9
Specific capacity (gal/min)/ft of drawdown)							
0.01-1.0	1	1	3	3	-	1	9
1.1 -9.8	1	1	1	3	-	1	7
9.9 -35	3	3	6	3	-	-	15

Yield data are available for only 12 of these 17 wells. The yields of the 12 wells that tap these geologic units range from less than 1 to 120 gal/min; the median yield is 11 gal/min. Only 2 of the 12 wells yield more than 50 gal/min. This apparent anomaly indicates that, if water is not obtained above a depth of 400 ft in the rocks that are normally good aquifers, then chances are poor for obtaining high yields below a depth of 400 ft.

Since June 1984, the West Virginia Department of Health has required that well drillers submit well-completion reports to the county health departments after drilling a well. The report contains a driller's log and other information, such as well-construction and yield information. The various ranges of well-depth and well-yield data from the recent well-completion reports are compared to the older well data in the GWSI data base in table 4. The well-completion reports show that most of the wells drilled in Jefferson County since 1984 are cased and grouted at depths greater than 20 ft. Water enters the well through the open borehole below the grouted casing. Only 2 percent of the wells drilled since 1984 are less than 100 ft deep, whereas about 60 percent of the older GWSI wells are less than 100 ft deep. This indicates that the shallow water is being cased off in the newer wells in order to tap deep water-bearing zones that are not readily affected by contaminants infiltrating from land surface.

Water Use

Total ground-water use in Jefferson County in 1988 was estimated to be 9 Mgal/d (Jefferson County Planning Commission, 1986, p. II-20,21; Kelley, Gidley, Blair, and Wolfe, Inc., 1986, appendix B, p. 7-10; and unpublished data of the U.S. Geological Survey). Approximately 30 public supply systems in Jefferson County supply approximately 1.83 Mgal/d of ground water and approximately 0.5 Mgal/d of surface water to approximately 24,000 people. The remaining 17,000 people in the county rely on wells and springs that supply approximately 0.85 Mgal/d of ground water. Ground water used for public and rural domestic supply is about 31 percent of the total ground water used in the county (table 5).

Table 4.--Percentage of wells in specific depth and yield ranges

[Well data from West Virginia Department of Health (DOH) files and U.S. Geological Survey Ground-Water Site Inventory (GWSI) data base. --, no data available]

Geologic unit	Source of data	Number of wells	Depth (feet) 0 - 100	101 - 399	400 - 800	Number of wells	Yield (gallons per minute) 1 - 10	11 - 50	51 - 100	101 - 600
			Percents				Percents			
Chambersburg Limestone of the Trenton Group	DOH	6	0	83	17	6	50	33	17	0
	GWSI	16	50	44	6	7	71	29	0	0
Beekmantown Group	DOH	20	10	80	10	20	30	65	5	0
	GWSI	65	39	52	9	20	35	35	20	10
Conococheague Formation	DOH	37	0	70	30	37	43	54	3	0
	GWSI	135	46	46	8	47	40	36	11	13
Elbrook Formation	DOH	21	0	81	19	21	19	71	10	0
	GWSI	71	18	78	4	20	15	70	10	5
Waynesboro Formation & some Tomstown Dolomite	DOH	21	0	100	0	21	28	67	5	0
	GWSI	19	47	42	11	8	75	25	0	0
Tomstown Dolomite	DOH	2	--	--	--	2	--	--	--	--
	GWSI	34	35	65	0	9	44	44	12	0

In 1988, agricultural water use was about 2.15 Mgal/d (about 25 percent of the total ground water used in the county). The water used at the Leetown Fisheries accounts for approximately half of the water used in this category. On an annual basis, about 0.58 Mgal/d of ground water is used for irrigating crops and applying pesticides to orchards, but most of this water is used from April through October. Therefore, during this 5- to 6-month growing season, about 1.16 Mgal of ground water is used each day. Although some of this water returns to the ground-water system, most of it is consumed by evapotranspiration.

In 1988, industrial ground-water use was about 3.69 Mgal/d (about 42 percent of the total ground water used in the county). Of this amount, approximately 2.0 Mgal/d is pumped out of limestone quarries into streams during mining operations. Actual pumping from the quarries varies from 1 to 4 Mgal/d (Kelley, Gidley, Blair, and Wolfe, Inc., 1986, appendix B, p. 7 and 9), depending on the recharge from rainfall.

Table 5.--Ground-water use in 1988 for Jefferson County, West Virginia

[Values in million gallons per day]

Public water supply	1.83
Rural domestic	.85
Agriculture	
Fisheries	1.10
Dairy facilities	.47
Irrigation (spray arch)	.58
Industry	1.69
Mining	2.00
Commercial (motels, schools)	.20
Total	8.72

In 1988, commercial and institutional water use was about 0.20 Mgal/d (about 2 percent of the total ground water used in the county). The relative amounts of water used from the various geologic units by the major water users in the county is shown in figure 15.

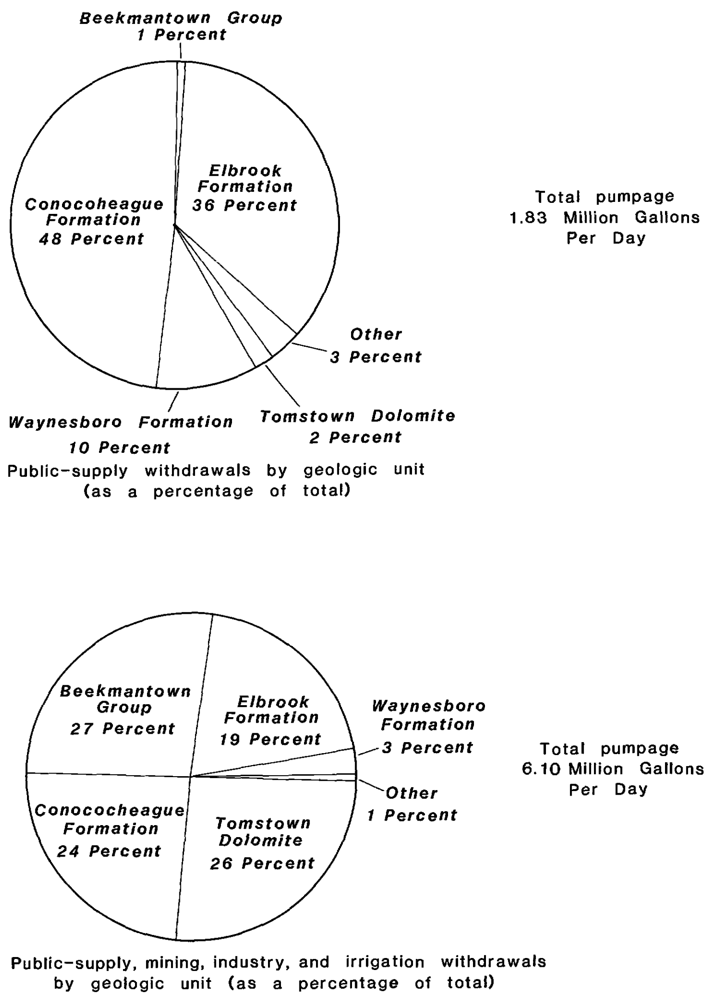


Figure 15.-- Ground-water withdrawals by geologic unit in Jefferson County, West Virginia.

WATER QUALITY

Water quality in the study area was evaluated by use of several different sampling networks. A ground-water-sampling network of 62 wells and 8 springs was sampled in July 1988 to determine ground-water quality and changes in water quality since 1974. In May 1989, 25 ground-water sites that were sampled in 1974 were resampled to determine the effects of elevated water levels and recent fertilizer applications on water quality. A sampling network of three wells, two springs, and two streams was sampled quarterly (every 3 months for 1 year) to document seasonal water-quality changes. A surface-water network of 13 streams was resampled during low-flow conditions in August and September of 1988 to determine surface-water quality and flow as well as changes in water quality since 1974.

Ground-Water-Sampling Network

A ground-water-quality sampling network of 62 wells and 8 springs was established to document present ground-water quality and changes in ground-water quality that may have occurred since 1974 (Hobba, 1981) (fig. 16). High nitrate concentrations were previously reported for 30 of the sites. Sixty-three samples were from wells and springs in the carbonate areas; seven samples were from wells in the noncarbonate areas.

The wells were pumped until water temperature, pH, and specific conductance had stabilized. The springs were sampled near points of maximum flow. Standard U.S. Geological Survey sampling techniques were used (Wood, 1976). Water temperature; specific conductance; pH; concentrations of dissolved oxygen, carbonate alkalinity, bicarbonate alkalinity, and total alkalinity; and fecal coliform and fecal streptococcal bacteria counts were measured in the field (appendix B-1). The bacteria samples were collected, incubated, and analyzed according to standard microbiological sampling techniques (Britton and Greeson, 1988). The U.S. Geological Survey Central Laboratory in Denver, Colorado, analyzed the samples for concentrations of nutrients (nitrogen and orthophosphorous species), dissolved calcium, magnesium, sodium, potassium, chloride, sulfate, fluoride, silica, iron, and manganese. Additional water samples collected at 26 wells and 4 springs were analyzed for the organochlorine and organophosphate classes of pesticides. The detection limits of these pesticides are given in table 6; the analyses are given in appendix B-5.

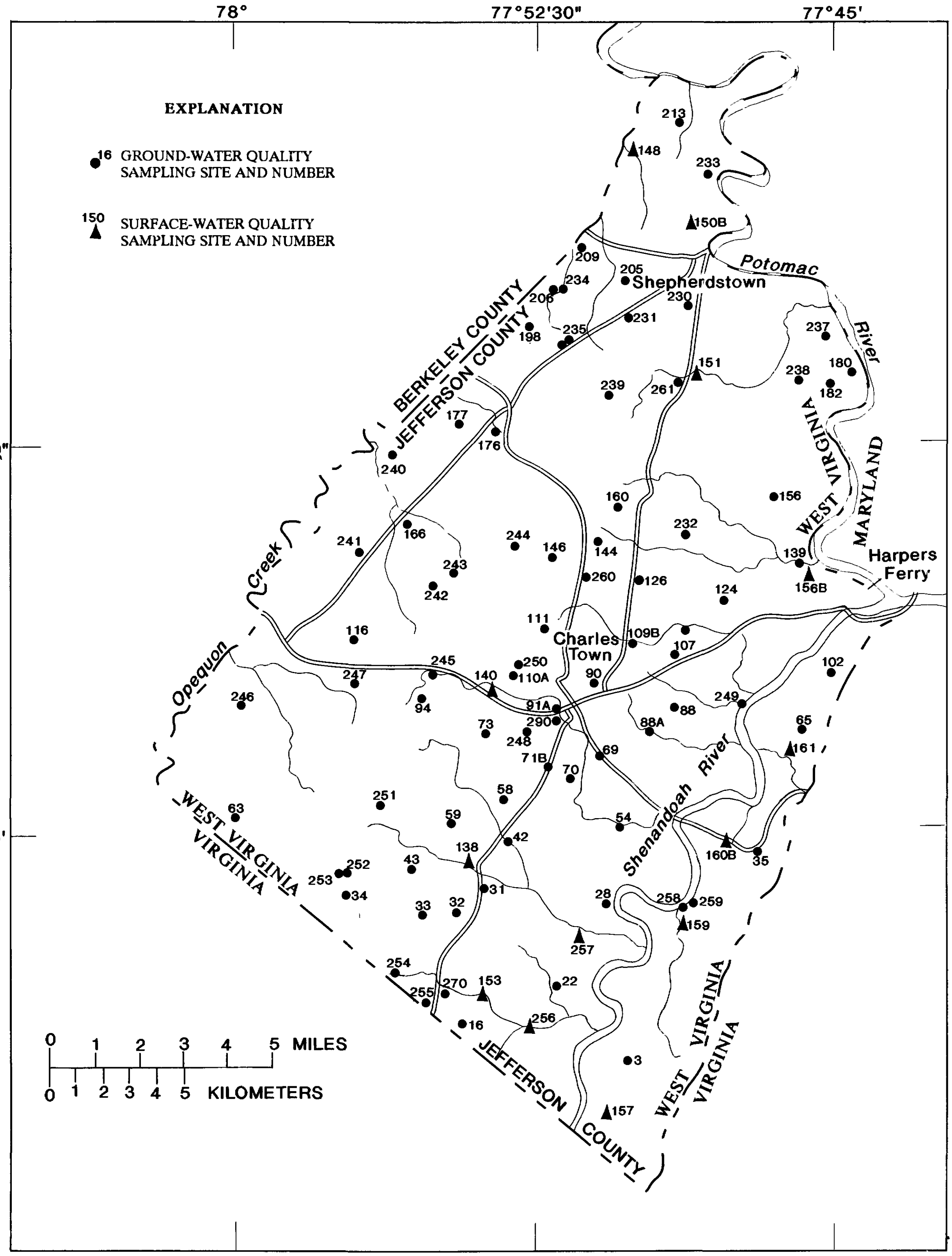


Figure 16.-- Location of water-quality sampling sites in Jefferson County, West Virginia.

Table 6.--Selected pesticides, polychlorinated biphenyls and polychlorinated naphthalenes, and their detection limits

[Only two samples were analyzed for triazine pesticides. PCB, polychlorinated biphenyls; PCN, polychlorinated naphthalenes; µg/L, micrograms per liter]

Compound	Class	Detection limit (µg/L)	Type of compound
Chlorpyrifos	Organophosphorous	0.010	Insecticide
Diazinon	Do.	.010	Do.
Disulfoton	Do.	.010	Do.
Ethion	Do.	.010	Do.
Fonofos	Do.	.010	Do.
Malathion	Do.	.010	Do.
Methyl Parathion	Do.	.010	Do.
Methyl Trithion	Do.	.010	Do.
Parathion	Do.	.010	Do.
Phorate	Do.	.010	Do.
Trithion	Do.	.010	Do.
Aldrin	Organochlorine	.001	Do.
Chlordane	Do.	.100	Do.
DDD	Do.	.001	Do.
DDE	Do.	.001	Do.
DDT	Do.	.001	Do.
Dieldrin	Do.	.001	Do.
Endosulfan	Do.	.010	Do.
Endrin	Do.	.001	Do.
Heptachlor	Do.	.001	Do.
Heptachlor Epoxide	Do.	.001	Do.
Lindane	Do.	.001	Do.
Methoxychlor	Do.	.010	Do.
Mirex	Do.	.010	Do.
Perthane	Do.	.100	Do.
Toxaphene	Do.	1.000	Do.
Alachlor	Triazine	.100	Herbicide
Ametryn	Do.	.100	Do.
Atrazine	Do.	.100	Do.
Cyanazine	Do.	.100	Do.
Metolachlor	Do.	.100	Do.
Metribuzin	Do.	.100	Do.
Prometon	Do.	.100	Do.
Prometryn	Do.	.100	Do.
Propazine	Do.	.100	Do.
Simazine	Do.	.100	Do.
Simetryn	Do.	.100	Do.
Trifluralin	Do.	.100	Do.
PCB'S	Organochlorine	.100	Industrial
PCN'S	Do.	.100	Do.

At 57 (or 81 percent) of the 70 sites sampled, U.S. Environmental Protection Agency (USEPA) maximum contaminant levels (MCL)[1/] (U.S. Environmental Protection Agency, 1988a), secondary maximum contaminant levels (SMCL)[1/] (U.S. Environmental Protection Agency, 1988d) or maximum contaminant level goals (MCLG)[1/] (U.S. Environmental Protection Agency, 1988b) were exceeded for one or more of the following constituents:

Constituent	Environmental Protection Agency's drinking water regulation	Number of samples exceeding MCL, MCLG or SMCL	Percentage of samples exceeding MCL, MCLG or SMCL
	(MCL)		
Nitrate as nitrogen	10 milligrams per liter	18	26
	(MCLG)		
Fecal coliform bacteria	0 colonies per sample	37	53
Fecal streptococci bacteria	0 colonies per sample	48	70
	(SMCL)		
Chloride	250 milligrams per liter	1	1
Manganese	50 micrograms per liter	8	11
Sulfate	250 milligrams per liter	2	3

1/ The National Primary Drinking Water Regulations promulgated by the U.S. Environmental Protection Agency in 1976 defines the maximum permissible level of a contaminant or maximum contaminant level (MCL) in water delivered to a public-water-supply user. These regulations, which are designed to safeguard public health and welfare, are based on the toxicity or carcinogenicity of the contaminant (U.S. Environmental Protection Agency, 1976). The secondary maximum contaminant level (SMCL) is a recommended standard for potable water based on aesthetic considerations such as taste, odor, and appearance. The maximum contaminant level goal (MCLG) is a nonenforceable health-based goal that is to be set at the level at which, over a lifetime of exposure, would result in no adverse health effects.

Of the 18 wells that exceeded the USEPA MCL for nitrates, 16 also exceeded the USEPA MCLG for either fecal coliform or fecal streptococcal bacteria. A statistical summary of the ground-water water-quality constituents is presented in table 7. The complete water-quality analyses are presented in appendix B.

Table 7.--Statistical summary of ground-water-quality data collected in 1988 in Jefferson County, West Virginia

[mg/L, milligrams per liter; ug/L, micrograms per liter; mL, milliliters; uS/cm, microsiemens per centimeter at 25 degrees Celsius]

Constituent	Mean	Median	Maximum	Minimum
Hardness mg/L as $CaCO_3$	340	330	680	30
Specific conductance uS/cm	672	640	1,550	89
Dissolved oxygen mg/L	4.4	5.4	9.6	0.3
pH standard units	7.1	7.2	7.9	5.9
Alkalinity mg/L as $CaCO_3$	270	280	440	15
Carbonate mg/L as CO_3	0	0	0	0
Bicarbonate mg/L as HCO_3	330	340	530	18
Ammonia mg/L as N	0.15	0.02	7.7	<.01
Nitrite mg/L as N	.03	.01	1.1	<.01
Nitrate mg/L as N	8.2	5.8	63	<.10
Nitrite + nitrate mg/L as N	8.2	5.8	63	<.10
Phosphorous mg/L as P	.05	.01	0.48	<.01
Calcium mg/L as Ca	98	94	210	5.7
Magnesium mg/L as Mg	22	22	60	3.7
Potassium mg/L as K	4.0	2.5	18	.4
Chloride mg/L as Cl	22	12	270	1.3
Sulfate mg/L as SO_4	40	27	490	5.2
Fluoride mg/L as F	.3	.2	1.1	<.1
Silica mg/L as SiO_2	13	12	27	6.5
Iron ug/L as Fe	57	10	2,000	<3
Manganese ug/L as Mn	40	1	680	1
Fecal coliform colonies/100 mL	120	1	4,400	<1
Fecal streptococci colonies/100 mL	220	6	6,000	<1
Dissolved solids mg/L	414	393	1,230	65
Sodium mg/L as Na	9.6	5.8	70	1.2

Nitrate and Chloride

The mean concentration of nitrate (as nitrogen) for the 70 sites sampled was 8.2 mg/L (milligrams per liter); the median concentration was 5.8 mg/L. Nitrate concentrations ranged from about 0.1 mg/L to 63 mg/L (table 7). Of the 70 sites sampled, 26 percent (18) exceeded the USEPA MCL (10 mg/L). Of these 18 sites, 15 are in areas that were reported as having high nitrate levels in 1974 (Hobba, 1981), and 14 of the 18 sites are located on cattle, dairy, or hog farms, where animal manure is produced and applied to fields.

It was thought that a sudden increase in water levels might affect the concentration of nitrates in ground water. On May 1, 1989, the lowest water level in the Martinsburg observation well was 51.91 ft below land surface. From May 1 to May 18, 7.08 in. of rain fell at the Martinsburg precipitation station (National Oceanic and Atmospheric Administration, 1989). On May 18, water levels in the Martinsburg observation well peaked at 36.56 ft below land surface. Sixteen wells that had been sampled in July 1988 were resampled from May 22 to May 25, 1989, and analyzed for nitrates.

Nonparametric statistics were used to analyze the 16 sites that were sampled in both 1988 and 1989. The statistical analyses indicated that the concentration of nitrates, at the 95-percent confidence level, increased significantly (by 9.4 percent) from 14.1 mg/L in 1988 to 15.6 mg/L in 1989. Of the 16 sites, 13 had increased concentrations of nitrate, 2 had decreased concentrations, and 1 was unchanged. Although there may be a correlation between increasing water levels and increasing concentrations of nitrate, there also may be a correlation between increasing concentration of nitrate and the applications of manure or fertilizer. Gerhart (1986, p. 489) concluded for a geologically similar area in Pennsylvania underlain by carbonate rocks that "The amount of fresh manure on the land surface at the time of the storm determines whether nitrate concentrations [in ground water] increase or decrease, as well as the magnitude of the increase or decrease."

Chloride concentration can be used to distinguish between organic and inorganic nitrogen fertilizers as possible nitrate sources (Charles Spiro, Department of Agriculture, West Virginia University, oral commun., 1989). Organic sources of nitrogen, such as manure from cattle, typically contain high concentrations of chloride, because of the dietary supplements given to beef and dairy cattle. Inorganic fertilizers, such as anhydrous ammonia, generally do not contain concentrations of chloride.

The mean concentration of chloride for the 70 sites sampled was 22 mg/L; the median concentration was 12 mg/L. Chloride concentrations ranged from less than 1.3 mg/L to 270 mg/L (table 7). The USEPA SMCL for chloride (250 mg/L) was exceeded in only one sample. In the 18 wells where nitrate concentrations exceeded 10 mg/L, the mean chloride concentration was 40 mg/L. The mean concentration of chloride was 15.7 mg/L for the 52 sites where nitrate concentrations were less than or equal to 10 mg/L. Elevated concentrations of chloride, in conjunction with known land use, indicate that the high concentrations of nitrate may be attributable to manure from livestock feedlots, quarters, storage lagoons, and dairies.

Bacteria

Fecal coliform and fecal streptococcal bacteria are indicators of potential bacterial or viral contamination, because water that contains these bacteria can also contain pathogenic bacteria or viruses. The USEPA MCLG for fecal coliform and fecal streptococcal bacteria is 0 colonies per sample.

Of the 70 ground-water sites sampled, 37 samples (53 percent) contained one or more fecal coliform colonies per 100 mL of sample. The mean fecal coliform count was 120 colonies per 100 mL of sample; the median count was 1 colony per 100 mL (table 7).

Of the 69 fecal streptococcus samples available (one sample was lost), 48 (70 percent) contained one or more fecal streptococcus colonies per 100 mL of sample. The mean fecal streptococcus count was 220 colonies per 100 mL of sample; the median count was 6 colonies per 100 mL (table 7).

The ratio of fecal coliform to fecal streptococcal bacteria can be used to distinguish between human and animal sources. A ratio greater than 4 is indicative of human sources; a ratio of less than 0.7 is indicative of animal sources (American Public Health Association and others, 1980, p. 819). Four samples had fecal coliform to fecal streptococcus ratios greater than 4 (human sources); 34 samples had ratios of less than 0.7 (animal sources). This indicates that most of the bacterial contamination is associated with animal wastes.

Manganese and Dissolved Oxygen

The mean concentration of manganese for the 70 sites sampled was 40 μg/L (micrograms per liter); the median concentration was 1.0 μg/L. Manganese concentrations ranged from 1 to 680 μg/L (table 7). Eight samples (11 percent) exceeded the USEPA SMCL (50 μg/L). The mean concentration for the eight samples was 317 μg/L. The SMCL for manganese was not exceeded in water from sampled springs.

High concentrations of manganese were not limited to any particular geologic formation. Most of the samples that contained high concentrations of dissolved manganese had a dissolved oxygen concentration of less than 2 mg/L. The mean dissolved oxygen concentration for the eight sites at which the USEPA SMCL was exceeded was 1.9 mg/L; the mean dissolved oxygen concentration for the 70 sites was 4.4 mg/L; therefore, a correlation between high concentration of manganese and low concentration of dissolved oxygen is indicated.

Pesticides

Of the 29 sites sampled in July 1988, water from 9 sites (6 wells and 3 springs) contained concentrations of pesticides greater than the detection limit (fig. 17). Eight of the nine sites were from wells and springs in or near orchards, and the other site was a spring in a pasture.

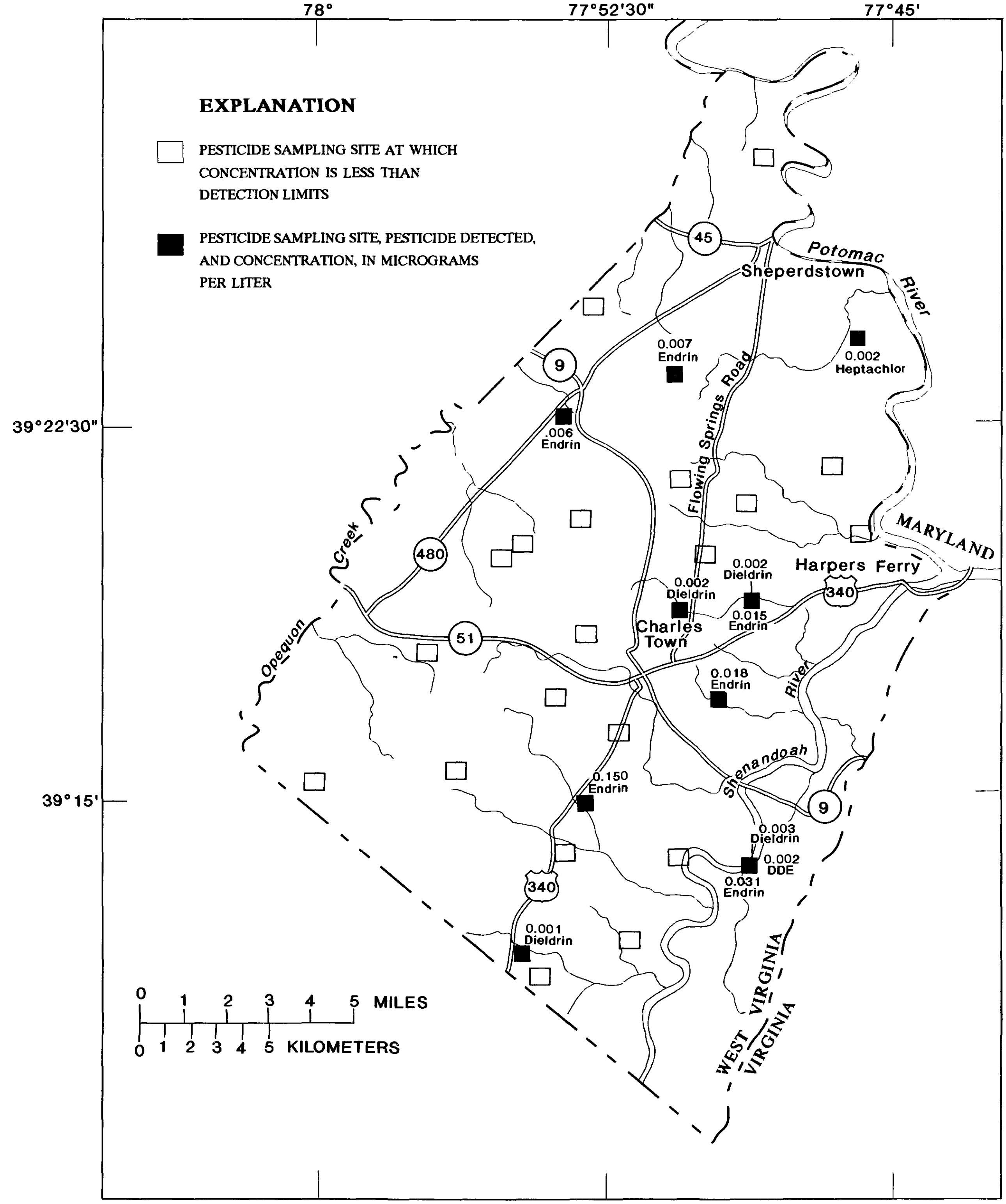


Figure 17.-- Location of July 1988 pesticide sampling sites and concentrations of pesticides detected in Jefferson County, West Virginia.

Of the 22 pesticides (table 6) analyzed for in the organochlorine and organophosphate classes, only 4 were detected—DDE (a metabolite of DDT), endrin, dieldrin, and heptachlor. All four are organochlorine pesticides, which are very stable compounds, are persistent in the environment, have a high affinity for adsorption to organic matter, and are highly immobile in soils (Council for Agricultural Science and Technology, 1985). DDT, endrin, dieldrin and heptachlor were removed from the USEPA approved list of pesticides during the early 1970's to early 1980's (U.S. Environmental Protection Agency, 1985). Prior to their removal, DDT, endrin, and dieldrin were commonly used in orchards and on certain crops such as corn and alfalfa. Heptachlor was commonly used in conjunction with chlordane for termite control.

Endrin was detected in six samples. None of the samples contained concentrations in excess of the USEPA MCL for endrin in domestic water supplies (0.2 μg/L). Heptachlor was detected in one sample. There is no MCL for heptachlor in domestic water supplies, but the proposed MCL is 0.4 μg/L (U.S. Environmental Protection Agency, Office of Drinking Water, written commun., 1988). Dieldrin was detected in four samples. There is no MCL or proposed MCL for dieldrin. DDE was detected in one sample. In 1989, there were no limiting regulations for the DDT metabolites DDD and DDE. However, the U.S. Public Health Service drinking-water standards set the maximum permissible concentrations for DDT, dieldrin, and heptachlor at 42, 17, and 18 μg/L, respectively (U.S. Public Health Service, written commun., 1971).

Radon

Of the 70 sites sampled for complete chemical analysis in July 1988, 4 were sampled for radon (appendix B-1). Radon 222 is a radioactive gas and a known carcinogen, but currently no MCL has been set. The USEPA plans to establish a MCL for radon in drinking water by September 1990 (Jeff Hass, U.S. Environmental Protection Agency, oral commun., 1990).

Radon concentrations in the four samples analyzed ranged from 850 to 8,700 pCi/L (picocuries per liter). Concentrations at three sites in the metamorphic sandstones and shales east of the Shenandoah River were 2,300, 8,700, and 3,100 pCi/L. The concentration at the fourth site in the carbonate rocks was 850 pCi/L.

Changes in Water Quality

County planners are concerned that agricultural practices, changes in land use, and increases in population are causing increases in concentrations of nitrate, chloride, and bacteria in the ground water. To evaluate any changes in the concentrations of these constituents since 1974, water-quality data collected in 1974 were statistically compared to the water-quality data collected in 1988.

In 1974, 218 wells and springs in Jefferson County were sampled and analyzed for pH, specific conductance, water temperature, and concentrations of chloride, hardness, and nitrate; but only 18 of these sites were analyzed for fecal coliform and fecal streptococcal bacteria. In 1988, only 5 of the 18 sites sampled in 1974 could be resampled. The 1974 and 1988 common-data sets of five samples are too small to be representative of significant changes in bacteria levels throughout the county.

A large number of analyses from 1974 and 1988 contained data on chloride and nitrate concentrations. Therefore, it was possible to make a statistical comparison of these constituents. Histograms for four data sets—nitrates for 1974 and 1988 and chlorides for 1974 and 1988—indicated that the data were not normally distributed; therefore, the Wilcoxon signed ranks and nonparametric tests were used for data analyses (PSTAT Inc., 1983).

The sites sampled in 1988 were primarily those where concentrations of nitrate (as nitrogen) exceeded 10 mg/L in 1974. Therefore, the 1988 data sets for both nitrate and chloride are biased towards sites having nitrate concentrations of 10 mg/L or higher. To eliminate this bias, only 37 sites that were sampled for nitrates in both 1974 and 1988 were compared.

In 1974, the mean nitrate concentration for the 37 sites was 8.5 mg/L; the median concentration was 5.2 mg/L. In 1988, the mean nitrate concentration was 10.1 mg/L; the median was 6.7 mg/L. The results of the Wilcoxon signed ranks test (at an alpha level of 0.05) indicate that there are no significant differences between the 1974 and 1988 data sets (PSTAT Inc., 1983).

The same 37 sites that were sampled and analyzed for concentrations of nitrate in both 1974 and 1988, also were analyzed for chloride concentrations. In 1974, the mean chloride concentration for the 37 sites was 22 mg/L; the median was 12 mg/L. In 1988, the mean chloride concentration for the 37 sites was 25 mg/L; the median was 13 mg/L. The results of the Wilcoxon signed ranks test (at an alpha level of 0.05) indicate that there are no significant differences between the 1974 and 1988 chloride data sets (PSTAT Inc., 1983).

Although no statistically significant changes in overall nitrate or chloride concentrations are apparent when comparing the 1974 and 1988 data sets, changes are evident within the data sets (table 8). Of the 37 sites that were sampled for nitrates in both years, concentrations at 20 sites increased, concentrations at 15 sites decreased, and no change occurred at 2 sites in 1988. Of the 37 sites that were sampled for chloride concentrations, concentrations at 20 sites increased, concentrations at 15 sites decreased, and no change occurred at 2 sites in 1988.

Surface-Water Sampling Network

Water samples were collected for 13 surface-water sites in the county during low-flow periods in August and September 1988. The samples were analyzed for concentrations of dissolved calcium, magnesium, hardness, chloride, and nitrate-nitrogen. Specific conductance, pH, and water temperature were measured in the field. Discharge measurements were made at the time of sampling.

The 13 sites included 7 small tributaries in the carbonate valley and 4 small tributaries in the noncarbonate rocks of the Blue Ridge physiographic province (fig. 16). Data from two National Stream Quality Accounting Network (NASQAN) sites—the Potomac River at Sheperdstown and the Shenandoah River at Millville—also were available. The Potomac and Shenandoah Rivers have large drainage basins that receive drainage from carbonate and noncarbonate rocks. The streams draining the noncarbonate rocks of the Blue Ridge had the

Table 8.--Comparison of nitrate and chloride concentrations in ground water in 1974 and 1988 for Jefferson County, West Virginia (See figure 16 for locations of sampling sites.)

[mg/L, milligrams per liter]

Map site number	Latitude	Longitude	1974 Chloride (mg/L as Cl)	1988 Chloride (mg/L as Cl)	Change from 1974 to 1988	1974 Nitrogen, NO_2+NO_3 (mg/L as N)	1988 Nitrogen, NO_2+NO_3 (mg/L as N)	Change from 1974 to 1988
03	39 10 35 N	077 50 14 W	1.5	6.7	Increase	0.54	7.5	Increase
16	39 11 18 N	077 54 24 W	29	17	Decrease	16	12	Decrease
22	39 12 00 N	077 52 03 W	10	13	Increase	2.3	16	Increase
28	39 13 37 N	077 50 44 W	1.7	4.2	Increase	.03	0.24	Increase
31	39 13 54 N	077 53 49 W	50	46	Decrease	30	25	Decrease
32	39 13 28 N	077 54 31 W	12	12	No change	17	15	Decrease
33	39 13 25 N	077 55 26 W	28	5.4	Decrease	3.6	6.2	Increase
34	39 13 47 N	077 57 20 W	18	21	Increase	9.2	19	Increase
35	39 14 36 N	077 46 57 W	1.5	1.3	Decrease	.01	<.10	No change
42	39 14 49 N	077 53 14 W	12	16	Increase	3.7	9.5	Increase
43	39 14 18 N	077 55 41 W	140	270	Increase	35	13	Decrease
54	39 15 05 N	077 50 25 W	8.7	10	Increase	4.5	7.9	Increase
63	39 15 20 N	078 00 08 W	5.8	18	Increase	4.5	14	Increase
65	39 16 57 N	077 45 48 W	2.2	2.2	No change	.04	.11	Increase
69	39 16 27 N	077 50 55 W	12	10	Decrease	8.6	4.5	Decrease
70	39 16 02 N	077 51 41 W	6.8	6.6	Decrease	3.5	3.4	Decrease
73	39 16 57 N	077 53 48 W	3.1	40	Increase	3.4	5.1	Increase
88	39 17 24 N	077 49 04 W	12	33	Increase	9.5	19	Increase
90	39 17 52 N	077 51 03 W	16	39	Increase	5.4	3.3	Decrease
94	39 17 37 N	077 55 26 W	27	16	Decrease	15	12	Decrease
102	39 18 02 N	077 45 05 W	10	19	Increase	4.1	4.6	Increase
106	39 18 54 N	077 48 46 W	13	11	Decrease	2.8	3.6	Increase
107	39 18 24 N	077 49 01 W	14	10	Decrease	6.9	4.1	Decrease
109	39 18 40 N	077 50 40 W	22	35	Increase	5.2	5.9	Increase
116	39 18 44 N	077 57 09 W	27	33	Increase	9.4	11	Increase
126	39 19 52 N	077 49 56 W	46	12	Decrease	2.6	1.5	Decrease
144	39 20 37 N	077 50 56 W	80	7.7	Decrease	10	12	Increase
146	39 20 19 N	077 52 09 W	19	18	Decrease	13	15	Increase
156	39 21 28 N	077 46 29 W	9.8	11	Increase	7.3	6.6	Decrease
160	39 21 17 N	077 50 29 W	38	47	Increase	3.2	1.9	Decrease
176	39 22 43 N	077 53 35 W	4.0	4.5	Increase	5.3	5.3	No change
180	39 23 52 N	077 44 33 W	72	41	Decrease	31	20	Decrease
182	39 23 38 N	077 45 05 W	27	62	Increase	17	63	Increase
198	39 24 48 N	077 52 41 W	3.5	4.6	Increase	4.0	6.7	Increase
205	39 25 41 N	077 50 16 W	5.7	3.2	Decrease	2.9	1.2	Decrease
209	39 26 18 N	077 51 24 W	5.5	7.2	Increase	4.5	5.0	Increase
213	39 28 43 N	077 48 54 W	17	15	Decrease	14	12	Decrease
			Summary of----- Increases and-- Decreases------		15 Decreases 2 No change 20 Increases			15 Decreases 2 No change 20 Increases

lowest concentrations of the common dissolved constituents and the highest water temperatures (table 9). The noncarbonate rocks in the Blue Ridge are composed primarily of metamorphosed sandstones and shales, and there is very little agriculture. The higher concentrations of ammonia, nitrite, and nitrate in streams draining the carbonate areas (as compared to the noncarbonate areas) are probably attributable to agricultural activity. The higher specific conductance and concentrations of calcium and magnesium in streams draining the carbonate areas is attributable to the dissolution of the limestones and dolomites that comprise the carbonate aquifer.

Table 9.--Comparison of water quality of streams in carbonate and noncarbonate terranes

[Deg. C, degrees Celsius; uS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; <, less than]

Station name	Lithologic type	Temperature, water (deg C)	Discharge (cubic feet per second)	Specific conductance (uS/cm)	Oxygen, dissolved (mg/L)	pH (standard units)	Nitrogen, ammonia dissolved (mg/L as N)
Potomac River at Shepherdstown	Carbonate + noncarbonate	24.0	2,780	366	7.6	7.7	0.06
Shenandoah River at Millville	Carbonate + noncarbonate	23.0	659	408	6.2	7.6	.09
	Mean value	23.5	1,720	387	6.9	7.6	.08
Furnace Run nr Mountain Mission	Noncarbonate	26.5	1.3	52	6.4	7.7	.02
Rocky Branch nr Myerstown	Noncarbonate	24.0	0.10	37	6.0	6.8	.02
Forge Run nr Mountain Mission	Noncarbonate	24.5	.14	132	6.8	7.8	.03*
Shenandoah R Trib nr Silver Grove	Noncarbonate	23.5	.03	235	5.8	7.9	.02
	Mean value	24.6	.38	114	6.2	7.6	.02
Evitts Run nr Charles Town	Carbonate	20.5	2.2	495	6.1	7.6	.02*
Elks Run Trib nr Harpers Ferry	Carbonate	21.0	.10	625	7.1	8.1	.02
Long Marsh Run Trib nr Franklintown	Carbonate	22.0	2.3	540	7.3	7.8	.06*
Rattlesnake Run nr Shepherdstown	Carbonate	24.0	.48	260	>10	7.6	.83
Rockymarsh Run Trib nr Shepherdstown	Carbonate	26.0	1.4	595	5.8	8.1	.03*
Rockymarsh Run Trib nr Scrabble	Carbonate	14.0	2.2	555	6.0	7.1	.02
Bullskin Run nr Wheatland	Carbonate	20.0	4.0	510	7.8	7.6	.10
	Mean value	21.1	1.8	511	7.2	7.7	.15

Station Name	Date	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorous ortho, dissolved (mg/L as P)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Chloride, dissolved (mg/L as Cl)
Potomac River at Shepherdstown	09-01-88	0.01	1.3	0.04	47	9.8	22
Shenandoah River at Millville, WV	09-01-88	< .01	.55	.07	39	16	23
	Mean value	<.01	.92	.06	43	12	22
Furnace Run nr Mountain Mission	08-03-88	<.01	<.10	.01	4.6	2.1	2.4
Rocky Branch nr Myerstown	08-03-88	<.01	.17	<.01	2.7	1.7	1.6
Forge Run nr Mountain Mission	08-03-88	<.01*	.35*	.02*	15	5.6	3.5
Shenandoah R Trib nr Silver Grove	08-03-88	<.01	.27	<.01	29	9.7	6.2
	Mean value	<.01	<.22	<.01	13	4.8	3.4
Evitts Run nr Charles Town	08-04-88	.03*	3.3*	<.01*	95	7.3	12
Elks Run Trib nr Harpers Ferry	08-03-88	<.01	.99	.01	74	37	16
Long Marsh Run Trib nr Franklintown	08-03-88	.04*	6.1*	<.01*	96	12	10
Rattlesnake Run nr Shepherdstown	08-02-88	.13	4.1	.02	98	15	11
Rockymarsh Run Trib nr Shepherdstown	08-02-88	.03*	3.4*	<.01*	110	9.7	5.6
Rockymarsh Run Trib nr Scrabble	08-02-88	<.01	3.2	.02	100	12	9.0
Bullskin Run nr Wheatland	08-03-88	.03	4.2	.03	95	8.1	7.7
	Mean value	<.04	3.6	<.02	95	14	10

* These samples were spilled in shipment and resampled on August 25, 1988.

Streamflow also was less in streams draining the noncarbonate rocks in the Blue Ridge than in the streams draining the carbonate rocks. The metamorphic rocks have little primary or secondary porosity, and most of the precipitation runs off after storms instead of percolating into and recharging the aquifer. As a result, the ground water component of streamflow in the noncarbonate areas is less than that in the carbonate areas (Hobba and others, 1972).

The Shenandoah and Potomac Rivers drain carbonate and noncarbonate areas and the water quality for those rivers reflects the combination of these lithologies. Concentrations of chloride and phosphorous in the Shenandoah and Potomac Rivers were higher than in streams draining either the carbonate or noncarbonate areas. This is probably attributable to the discharge of chlorinated sewage effluent and phosphate detergents from upstream septic and sewage systems on both rivers. The concentrations of the remaining constituents were between the relatively high concentrations of the carbonate streams and the relatively low concentrations of the noncarbonate streams.

Quarterly Sampling Network

Three wells, two springs, and two spring-fed streams (fig. 18) were measured and sampled for water level, discharge, and water quality to determine if there were seasonal changes. All the sites were sampled quarterly beginning in September 1988 and ending July 1989. The samples were analyzed for nutrients, major ions, and bacteria; the two springs and two spring-fed streams also were analyzed for pesticides. Discharge measurements were made on the two springs and two spring-fed streams at the time of sampling (appendix B-3).

Precipitation for the period was not typical. Heavy rains (9.68 in.) during May 1988 increased ground-water levels and sustained streamflows during June and July. The departure of precipitation from normal for June 1988 through May 1989 was only 0.24 in. below normal. However, annual precipitation for 1988 would have been far below normal had precipitation during May been at or below the 3.6-in. normal.

Analysis of quarterly water-quality data for September 1988, December 1988, March 1989, and June 1989 revealed no significant increases or decreases in the concentrations of the common water-quality constituents. The only discernable change was a slight increase in concentrations of alkalinity and calcium at five of the seven sites during March 1989. Abnormal precipitation during the period may have masked seasonal changes in water quality.

Four of the seven sites—Bullskin Run at Kabletown, North Fork Long Marsh Run, Head Spring, and Aldridge Spring (fig. 18)—were sampled quarterly for organochlorine and organophosphate pesticides (table 6). DDT, DDD, and DDE were detected at North Fork Long Marsh Run (table 10); DDT, DDE, endrin, and parathion were detected at Bullskin Run at Kabletown (table 10); DDE and methyl parathion were detected at Head Spring (table 10); no pesticides were detected at Aldridge Spring. There is no USEPA MCL or proposed MCL for parathion or methyl parathion.

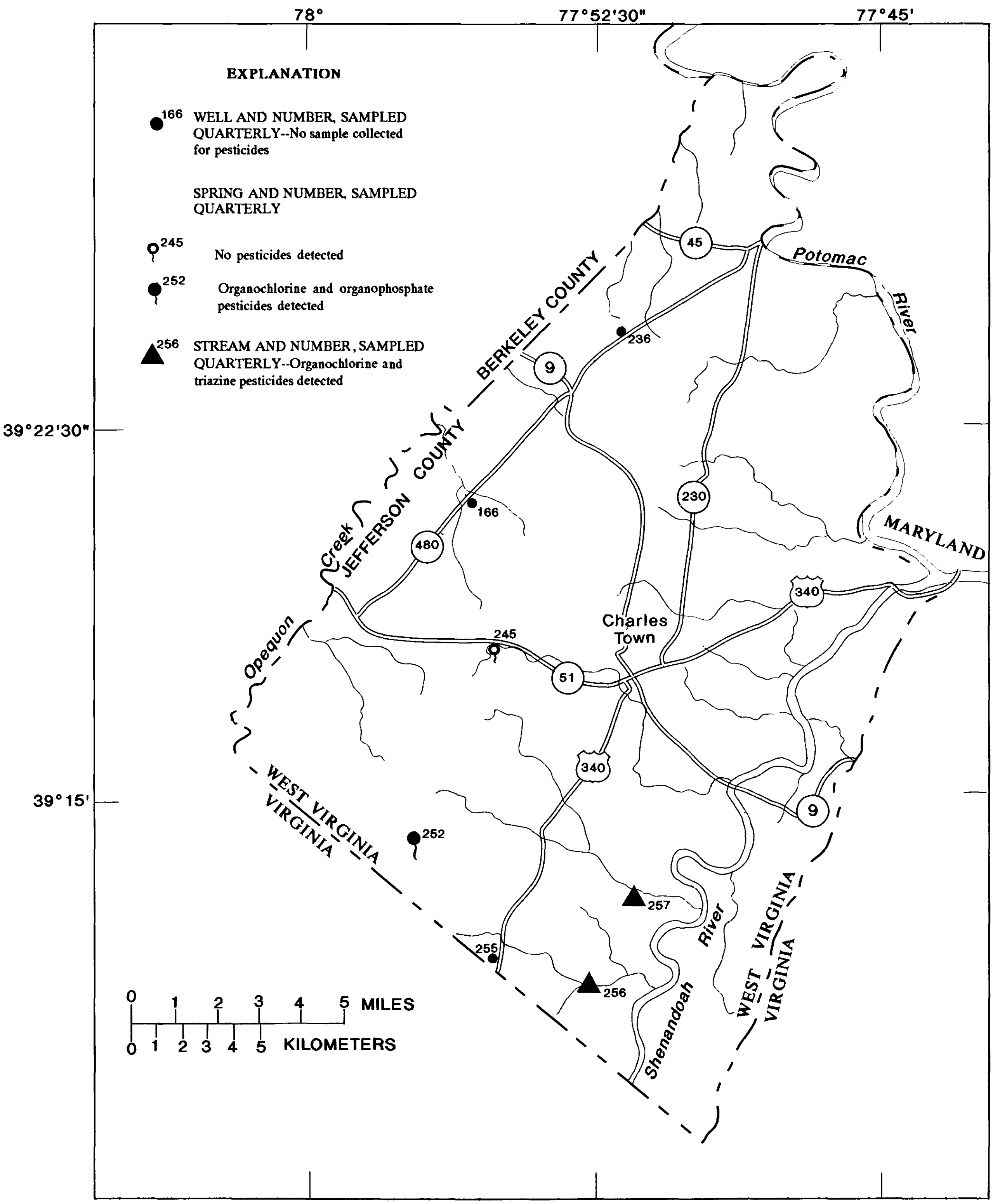


Figure 18.-- Location of wells and springs in the quarterly sampling network in Jefferson County, West Virginia.

Table 10.--Average annual constituent concentrations for Head Spring on Bullskin Run near Summit Point and Bullskin Run at Kabletown, West Virginia

[Deg C, degrees Celsius; uS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; ug/L, micrograms per liter; cols, colonies; mL, milliliters]

Station name		Temperature, water (deg C)	Discharge (cubic feet per second)	Specific conductance (uS/cm)	Oxygen, dissolved (mg/L)	PH (standard units)	Alkalinity Tot it field (mg/L as $CACO_3$)
Head Spring near Summit Point, WV	Mean concentration	13.5	0.56	480	8.7	7.5	220
Bullskin Run at Kabletown, WV	Mean concentration	14.8	13.8	559	9.9	7.8	240
	Percentage concentration change	+8.8	+96	+14	+12	+3.8	+10

Station name		Carbonate water (mg/L as CO_3)	Bicarbonate water (mg/L as HCO_3)	Nitrogen, ammonia (mg/L as N)	Nitrogen, nitrite (mg/L as N)	Nitrogen, NO_2+NO_3 (mg/L as N)	Phosphorous ortho (mg/L as P)	Calcium (mg/L as CA)
Head Spring near Summit Point, WV	Mean concentration	0	270	0.11	0.03	5.1	0.01	85
Bullskin Run at Kabletown, WV	Mean concentration	0	300	.06	.02	6.6	.01	90
	Percentage concentration change	0	+10	-45	-33	+23	0	+5.6

Station name		Magnesium (mg/L as mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Chloride (mg/L as Cl)	Sulfate (mg/L as SO_4)	Fluoride (mg/L as F)	Silica (mg/L as SiO_2)
Head Spring near Summit Point, WV	Mean concentration	7.4	2.3	2.4	5.8	12	0.1	11
Bullskin Run at Kabletown, WV	Mean concentration	14	4.6	2.6	12	18	.2	10
	Percentage concentration change	+47	+50	+7.7	+52	+33	+50	-9.1

Station name		Iron (ug/L as Fe)	Manganese (ug/L as Mn)	Coliform (cols./100 mL)	Streptococci (cols./100 mL)	Dissolved solids (mg/L)
Head Spring near Summit Point, WV	Mean concentration	13	9	1,300	1,300	267
Bullskin Run at Kabletown, WV	Mean concentration	13	9	2,400	1,000	296
	Percentage concentration change	0	0	+46	-23	+10

Parathion and methyl parathion are organophosphate pesticides. The organophosphate pesticides are less persistent in the environment (usually measured in weeks) than the organochlorine pesticides (measured in years). The persistence of parathion in soil is about 1 week (Council for Agricultural Science and Technology, 1985, p. 43); therefore, the detection of parathion and methyl parathion during the summer quarterly sampling probably can be attributed to a recent application to crops.

Because Bullskin Run at Kabletown and North Fork Long Marsh Run drain agricultural areas, and because they repeatedly tested positive for organochlorine pesticides, they were sampled once for triazine herbicides. Triazine herbicides are generally used for weed control in fields of corn and alfalfa. Triazine persistence in soils is generally 10 to 18 months (Council for Agricultural Science and Technology, 1985, p. 43). Atrazine, cyanizine, prometon and simazine (all are triazines) were detected in samples from both sites (appendix B-6); however, the concentrations detected were well below the USEPA drinking water equivalent levels of 123, 46, 525 and 175 μg/L, respectively. There is no MCL or proposed MCL for cyanazine, prometone, and simazine. The MCL for atrazine is 3.0 mg/L. (U.S. Environmental Protection Agency, Office of Drinking Water, written commun., 1988).

SUMMARY

Jefferson County, an area of about 212 mi^2, is a rapidly developing area in eastern West Virginia. About 86 percent of the county is underlain by carbonate rocks. Almost all of the farms, orchards, industrial areas, and many new housing subdivisions are in areas that are underlain by carbonate rocks. Thus, the emphasis of this study was on the geohydrology and quality of water in the carbonate area.

An analysis of springflow measurements made in July 1945 indicates that the most productive aquifers—the Chambersburg Limestone of the Trenton Group, the Beekmantown Group, and the Conococheague Formation—have yields that exceed 1,300,000, 290,000, and 175,000 (gal/d)/mi^2, respectively. These carbonate units also have the greatest density of mapped sinkholes (3.5 to 5 sinkholes per square mile of outcrop).

Five dye-tracer tests were conducted in the carbonate aquifers to determine rates and directions of ground-water flow. Results from the three dye-tracer tests that were considered successful indicate that ground water moves parallel to strike at a rate of 70 to 840 ft/d, and perpendicular to strike at a rate of 30 to 235 ft/d.

Flow rates based on the dye-tracer tests and streamflow measurements permitted areal estimates of hydraulic conductivity and transmissivity. Estimates of horizontal hydraulic conductivity parallel to strike are four to nine times greater than that perpendicular to strike. Estimates of transmissivity using streamflow and water-table gradients parallel to strike are 3,900 and 4,100 ft^2/d, whereas estimates of transmissivity perpendicular to strike are 800 and 1,100 ft^2/d.

Water samples collected in July 1988 from 62 wells and 8 springs were analyzed for most common dissolved constituents and fecal bacteria. Water from 57 of these 70 sites (81 percent) exceeded the U.S. Environmental Protection Agency maximum contaminant level (MCL) for nitrate, maximum contaminant level goal (MCLG) for bacteria, or secondary maximum contaminant level (SMCL) for chloride, manganese, or sulfate. Nitrate concentrations ranged from less than 0.1 mg/L to 63.0 mg/L; the median was 5.8 mg/L. The MCL of 10 mg/L was exceeded in about 26 percent of the samples. Chloride concentrations ranged from 1.3 to 270 mg/L; the median was 12.0 mg/L. The SMCL of 250 mg/L was exceeded in only one sample. There was no statistically significant change, at the 95-percent confidence level, in 1988 nitrate or chloride concentrations compared to concentrations at the same sources in 1974. Agricultural land use was the only factor that seemed to correlate with elevated concentrations of nitrate and chloride.

About 53 percent of the samples contained fecal coliform bacteria and 70 percent contained fecal streptococcal bacteria. The ratio of fecal coliform to fecal streptococci for 34 samples indicated animal sources, and only 4 samples had ratios indicative of human sources. The ratio of fecal coliform to fecal streptococcal bacteria indicates that bacterial contamination of ground water is primarily from animal wastes.

Water samples from 30 sites were analyzed for 22 pesticides of the organochlorine and organophosphate classes. The pesticides detected at these sites—DDE, endrin, dieldrin, and heptachlor—are very stable compounds that are highly immobile in the soil. Of the nine samples containing concentrations of pesticide greater than the detection limit, eight were from wells or springs in or near orchards.

Water samples from four sites were analyzed for radon-222. Three samples from the metamorphic sandstones and shales had concentrations of 2,300, 8,700, and 3,100 pCi/L. The fourth sample was from the carbonate rocks and had a concentration of 850 pCi/L.

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GLOSSARY

Certain Hydrologic Terms Defined
to Help Reader Understand Report

Hydrology, like most branches of science, has its own terminology. An understanding of certain terms is essential when reading the report on the hydrology of Jefferson County. The definitions here have been simplified and shortened as much as possible. Further definitions can be found in reports by Heath (1983) and Nutter (1973, p. 40-41).

Alkalinity—The capacity of a solution (generally water) to neutralize acid.

Anticline—An upward fold in the rocks.

Aquifer—Rock formation that contains sufficient saturated permeable material to yield significant amounts of water to wells or springs.

Aquifer, confined (or artesian)—An aquifier in which the water level in a well tapping a confined aquifer will rise above the top of the aquifer because of hydrostatic pressure.

Aquifer, unconfined—An aquifier in which the water level in a well tapping an unconfined aquifer will not rise above the water table.

Base flow—The flow of a stream when all water in the channel is derived from ground water.

Bedding plane—Any plane in sedimentary rock along which sediment was deposited simultaneously.

Calcareous—A term used to describe rocks that contain a high percentage of calcium carbonate.

Carcinogen—A substance or agent that produces or incites cancer.

Carbonate rocks—Rocks that are composed principally of calcium carbonate (limestone) or calcium-magnesium carbonate (dolomite).

Coefficient of storage—A coefficient that represents the volume of water an aquifer releases, or takes into storage, per unit surface area of the aquifer, per unit change in head.

Depression, cone of—The depression in the water table or other potentiometric surface caused by the withdrawal of water from a well.

Dip of rock strata—The angle between the horizontal and the bedding plane; dip is measured in a vertical plane at right angles to the strike of the bedding. (See strike of rock strata.)

Dissolution—The act or process of dissolving rock.

Drawdown in a well—The vertical lowering in water level in a well caused by pumping.

Dye tracer test—A test in which a fluorescent dye is injected into any aquifer and then springs and streams downgradient from the injection point are monitored for dye with activated charcoal dye detectors. The dye detectors generally are exchanged weekly and analyzed for the presence of dye, using a fluorometer and/or visual tests.

Evapotranspiration—Evaporation from water surfaces, plus transpiration from plants.

Fault—A fracture in the Earth's crust accompanied by displacement of one side of the fracture with respect to the other.

Fecal Coliform bacteria—A bacteria found in both human and animal intestines.

Fecal Streptococcal bacteria—A bacteria found in both animal and human intestines.

Flow, conduit—The flow of ground water along bedding planes, faults, and joints that have been enlarged into cavities or caverns by dissolution of the carbonate rocks.

Flow, diffuse—The flow of ground water along bedding planes, faults, and joints that have not been significantly enlarged by dissolution.

Flow, laminar—A flow of water in which the velocity at a given point is constant in magnitude and direction.

Flow, turbulent—A flow of water in which the velocity at a given point varies erratically in magnitude and direction.

Fluorescence—The emission of radiation by a substance (in this case, water) during exposure to external radiation.

Fluorescence, background—Existing fluorescence measured in water samples prior to conducting a dye tracer test.

Fracture—A break in rock that may be caused by compressional or tensional forces.

Gaining stream—A stream, or segment of a stream, that receives water from an aquifer. (See losing stream.)

Gradient, hydraulic—The change of pressure head per unit distance from one point to another in an aquifer.

Ground water—Water contained in the zone of saturation in the rock. (See surface water.)

Head—Pressure, expressed as the height of a column of water that can be supported by the pressure.

Histogram—A representation of a frequency distribution by means of a bar graph, whereby each bar width represents a given class interval and each bar height represents the number of occurrences within the class interval.

Homogeneous—An aquifer is homogeneous if its properties are identical everywhere within the aquifer.

Hydraulic conductivity—A measure of the capacity of a rock to transmit water. It is expressed as the volume of water (at the existing kinematic viscosity) that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Isotropic—An aquifer that exhibits the same properties with the same values when measured along axes in all directions.

Joints—System of fractures in rocks along which there has been no movement parallel to the fracture surface. In coal, joints and fractures may be termed "cleats."

Karstification—A process whereby the dissolution of carbonate rocks by water produces features of karst topography, including dry undrained depressions or basins, and sinkholes with or without visible openings.

Karst—A term applied to a geologic area having topographic features that develop as a result of underground solution of the carbonate rocks and diversion of surface water underground.

Laminar flow—(See Flow, laminar).

Lineaments—Linear features observed on topographic maps, aerial photographs or imagery (formed by the alignment of stream channels or tonal features in soil, vegetation, or topography) which may represent subsurface fracture zones.

Losing stream—A stream, or segment of a stream, that is contributing water to an underlying aquifer. (See gaining stream.)

MCL—Maximum contaminant level—An enforceable maximum permissible concentration of a contaminant in water that is delivered to any user of a public water system.

MCLG—Maximum contaminant level goal—A non-enforceable maximum permissible concentration of a contaminant in drinking water that is to be set at the level at which, over a lifetime of exposure, would result in no adverse health effects.

Metamorphic rocks—Pre-existing rocks altered by temperature, pressure, stress, and chemical environment.

Microsiemens—The unit used in reporting specific conductance of water per centimeter at 25°C.

Noncarbonate rocks—Rocks, such as sandstones and shales, that are composed principally of noncarbonate minerals.

Nonparametric statistics—A statistical procedure whereby the comparison is between distributions and not between parameters.

Perched water table—A saturated zone of rock separated from an underlying body of ground water by unsaturated rock.

Permeability, intrinsic—A measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient.

Pesticide—A chemical used to destroy pests such as insects and weeds.

pH—The negative logarithm of the hydrogen-ion concentration in the water.

Porosity, primary—Interstices that were created at the time the rocks were formed.

Porosity, secondary—Openings in the rock, such as fractures or solution channels, which formed after the rock was deposited.

Potentiometric surface—An imaginary surface that everywhere coincides with the static level of water in the aquifer.

Precipitation, atmospheric—Water in the form of hail, mist, rain, sleet, or snow that falls to the Earth's surface.

Recharge—That part of precipitation or surface water that infiltrates through the Earth's surface and eventually reaches the water table.

Recovery of water level in a pumped well—When pumping from a well ceases, the water level rises (or recovers) to some level higher than when being pumped.

Seepage measurements—Flow measurements made at various points along a stream to determine if the stream is losing or gaining water.

Sedimentary rocks—A rock derived from the consolidation of sediments.

Sinkhole—A closed depression formed by the collapse of soil and/or other overlying materials into a solution cavity in the underlying carbonate rocks.

Slug test—A well-testing method whereby a known volume or "slug" of water is suddenly injected into or removed from a well, and the decline or recovery of the water level is repeatedly measured at closely spaced intervals to determine hydraulic characteristics of the rocks penetrated by the well.

SMCL—Secondary maximum contaminant level—a non-enforceable recommended standard for drinking water based on aesthetic considerations such as taste, odor, and appearance.

Specific capacity—The rate of discharge of a well, divided by the drawdown of the water level in the well.

Specific conductance—The measured electrical conductance of a unit length and cross section of water, reported in microsiemens (μS/cm) per centimeter at 25°C.

Storage coefficient—A coefficient that represents the volume of water an aquifer releases or takes into storage per unit surface area of the aquifer, per unit change in head.

Strike of rock strata—The direction of a line formed by the intersection of the bedding and a horizontal plane. (See dip of rock strata.)

Surface water—Water on the surface of the Earth, including snow, ice, lakes, ponds, streams, and rivers. (See ground water.)

Syncline—A downward fold in the rocks.

Transmissivity—The rate at which water of a prevailing viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient.

Turbulent flow—(See Flow, turbulent).

Water table—That surface in an unconfined water body at which pressure is atmospheric; generally the top of the saturated zone.

Water year—A one-year period from October 1 of one year through September 30 of the next calendar year. A water year is designated by the year in which it ends.

APPENDIX A

Dye-Tracer Tests

Use of fluorescent dyes to trace ground-water movement has become a standard method for hydrologic investigations in karst areas. Fluorescent dyes are inexpensive, water soluble, stable in natural waters, nontoxic, and easily detected at low concentrations (Aley and Fletcher, 1976).

Results from qualitative dye-tracer tests can be used to determine point-to-point connections between input and recovery points, to estimate travel times under specific hydrologic and meteorologic conditions, and to delineate the boundaries of a ground-water basin. During a qualitative dye-tracer test, a discrete sample of water is "tagged" with an appropriate tracer, and expected resurgence points are monitored for the tracer-laden water (Mull and others, 1988). A more detailed discussion of fluorescent dyes and ground-water tracing is beyond the scope of this report. For additional information on this subject, the reader is referred to Jones (1984) and Mull and others (1988).

In Jefferson County, the dye-injection sites typically were large sinkholes that were believed to be hydraulically connected to the ground-water-flow system. The injection sites were accessible by vehicles, and springs and streams that could be monitored were located downgradient. Wells were not used for monitoring because there was no way to determine the degree or relation of their positions to the local ground-water-flow system.

Prior to injecting the dye, the injection sinkhole was flushed with approximately 1,000 gallons of water to test the suitability of the sinkhole as an injection site and to wash away any debris and/or sediment in the hole. After flushing, the dye was poured into the sinkhole, and an additional 1,000 gallons of water was used to flush the dye into the ground-water-flow system.

Passive detectors, 5-inch by 3-inch fiberglass screen pouches filled with #10 mesh activated cocoanut charcoal, were used to absorb the dye. In general, the detectors were placed in selected springs and streams in an 180-degree arc downgradient from the injection sinkhole. Any fluorometric dye that reached the monitored resurgence point would be absorbed onto the charcoal in the detector. All detectors were installed prior to injection of the dyes to eliminate possible contamination of the detectors while transporting and handling the dye. The detectors were collected and replaced every 3 to 14 days. Analysis of the earliest collected detectors was used to determine preinjection levels of natural background fluorescence.

After the detectors had been collected, they were analyzed for the presence of dye by a local consultant hired by the county. The detectors were washed with deionized water to remove sediment. An elutriation solution composed of 25 percent ammonium hydroxide, 25 percent distilled water, and 50 percent 1-Propanol was used to desorb the dye from the cocoanut charcoal (Jones, W.K., Environmental Data, written commun., 1988). The charcoal was exposed to the solution for 30 minutes to remove rhodamine WT dye and for 24 hours to remove fluorescein dye. A Turner Model-111[1/] filter fluorometer with a 546 nm (nanometers) primary filter and a 590 nm secondary filter was used to detect the presence of rhodamine WT in the elutriated solution (Scanlan, 1968).

Although background fluorescence in the rhodamine WT wavelengths was minimal, many things such as chlorophyll, animal urine, and antifreeze, to name but a few, fluoresce in the same wavelength as fluorescein. Therefore, the presence of fluorescein was determined by use of the fluorometer and visual analysis. The detectors were washed and elutriated as previously discussed, then, the fluorometer with a 2A+47B primary filter and a 2A12+65A secondary filter was used to analyze the elutriant for fluorescence. In addition, a measured amount of charcoal from the detector was placed in a test tube, 6 mL of the elutriation solution was added, and the test tube was placed in a dark room. After 24 hours, a light was shined on the sample. If fluorescein was present, a characteristic green color could be seen floating immediately above the charcoal. If the color was very apparent, it indicated that the sample was strongly positive for fluorescein.

As a quality-assurance check, after the consultant had finished his determinations, the unused charcoal from the detectors was analyzed again by the U.S. Geological Survey, using the same methods as stated above. In most instances, the determinations about the presence of dye were the same. In those instances where the results were in disagreement, the results were considered to be inconclusive, indicating that dye may or may not have been detected. High background fluctuations in the fluorescein wavelengths at most sites made absolute determination of the presence of fluorescein impossible. Therefore, all the results from the fluorescein dye-tracer tests were considered inconclusive. Tentative directions of ground-water movement and velocities were not determined from these tests and were not used for calculations or interpretations reported in the body of this report.

Tracer test A began on October 1, 1987, and ended on January 21, 1988. One-half gallon of rhodamine WT was injected into a sinkhole north of Ranson; nine springs and streams (expected dye resurgence points) south and east of the sinkhole (fig. A-1) were monitored using passive detectors. The detectors were collected and replaced every 4 to 10 days. Daily water samples were collected at two additional sites—A3 and A4.

Dye was detected at sites A1, A2, A3, A4, A5, A6, A7, A9, and A10 within 4 to 12 weeks. The fluorometer dial readings for the passive detectors from this tracer test are presented in table A-1. Dial readings for the daily water samples collected manually at sites A3 and A4 are presented in table A-2.

1/ Use of firm names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Table A-1.--Fluorometric data from the passive detectors from dye-tracer test A north of Ranson, West Virginia

[** indicates primary dye recovery, ## indicates secondary dye recovery, ND indicates no data available]

Tracer-test A - Rhodamine WT injected 10-01-1987									
Date	Spring site A1	Spring site A2	Stream site A5	Spring site A6	Spring site A7	Stream site A8	Stream site A9	Stream site A10	Stream site A11
10-06	11	4	7	4	5	ND	ND	ND	ND
10-10	9	4	9	4	4	ND	ND	ND	ND
10-15	6	4	8	5	5	ND	ND	ND	ND
10-20	5	5	5	4	4	4	5	4	4
10-24	4	6	7	4	5	5	6	4	4
10-31	14**	12**	6	4	6	7	11**	5	5
11-07	17	14	8	4	5	5	9	6	4
11-14	11	21	8	4	6	7	7	4	7
11-22	14	20	12**	4	4	8	9	5	5
11-25	9	10	8	4	4	6	5	4	6
12-05	12##	6	13##	4	5	9	7	7	7
12-12	11	7	8	6**	5	5	7	6	7
12-19	10	12##	9	5	8**	5	9	7	5
12-26	13	11	9	5	7	8	7	11**	5
01-02	10	7	6	4	5	7	9	6	7
01-09	9	6	7	4	7	4	8	5	6
Detection	Positive	Positive	Positive	Positive	Positive	Negative	Positive	Positive	Negative

Because the detectors were replaced periodically, it was not possible to determine exactly when the dye first arrived at the site; therefore, the estimated ground-water velocities are reported as a range. The estimated ground-water velocities for tracer test A ranged from 150 to 235 ft/d on the basis of positive recovery sites. Estimated ground-water-flow velocity to site A1 is 180 to 230 ft/d, site A2 is 180 to 235 ft/d, site A3 is 155 ft/d, site A5 is 190 to 225 ft/d, site A6 is 150 to 165 ft/d, site A7 is 180 to 195 ft/d, and site A10 is 190 to 205 ft/d. Although dye was detected at surface-water sites A4 and A9 (fig. A-1), these sites were not used to estimate velocities or determine directions of flow because it was not possible to determine the point or points where the dye entered the stream.

Tracer test B began on October 16, 1987, and ended on February 5, 1988. About 2 pounds of fluorescein dye were injected into a sinkhole east of Charles Town; nine expected dye-resurgence points were monitored by use of passive detectors (fig. A-2).

Fluorometric and visual analysis was ineffective for determining low concentrations of fluorescein because of large fluctuations in natural background fluorescence within the fluorescein wavelengths. Although dye could have been present at several resurgence points, absolute detection of the dye was not possible, and the results of the fluorescein traces are considered inconclusive.

Tracer test C began on February 19, 1988, and ended on July 8, 1988. One-half gallon of rhodamine WT was injected into a sinkhole near Rippon; nine expected dye resurgence points were monitored with passive detectors (fig. A-3). Dye was detected at seven sites C1, C3, C4, C6, C7, C8, and C9 after 14 to 18 weeks. Because the dial readings for sites C2 and C5 showed little fluctuation above natural background fluorescence, these sites were considered to

Table A-2.--Fluorometric data for water samples collected manually from dye-tracer test A north of Ranson, West Virginia

[** indicates primary dye recovery, ## indicates secondary dye recovery, ND indicates no data available]

Tracer-test A - Rhodamine WT injected 10-01-1987

Date	Well site A3	Stream site A4	Date	Well site A3	Stream site A4	Date	Well site A3	Stream site A4
10-01	5	6	11-08	6	6	12-16	7	6
10-02	5	6	11-09	6	6	12-17	7	6
10-03	5	6	11-10	6	6	12-18	6	7
10-04	5	6	11-11	6	6	12-19	7	7
10-05	5	6	11-12	6	6	12-20	9**	7
10-06	5	6	11-13	6	6	12-21	8	7
10-07	6	6	11-14	6	6	12-22	7	8##
10-08	5	6	11-15	6	6	12-23	7	9
10-09	5	6	11-16	6	6	12-24	6	7
10-10	5	7	11-17	6	6	12-25	6	8
10-11	5	6	11-18	6	6	12-26	ND	ND
10-12	5	6	11-19	6	6	12-27	ND	ND
10-13	6	6	11-20	6	6	12-28	ND	ND
10-14	5	6	11-21	6	6	12-29	ND	ND
10-15	5	6	11-22	6	6	12-30	ND	ND
10-16	5	6	12-23	6	6	12-31	ND	ND
10-17	ND	ND	11-24	6	6	01-01	6	6
10-18	ND	ND	11-25	6	8**	01-02	ND	ND
10-19	ND	ND	11-26	6	8	01-03	6	6
10-20	ND	ND	11-27	6	7	01-04	6	6
10-21	ND	ND	11-28	6	9	01-05	6	6
10-22	ND	ND	11-29	6	7	01-06	6	6
10-23	ND	ND	11-30	6	7	01-07	6	6
10-24	6	6	12-01	6	7	01-08	6	6
10-25	6	6	12-02	ND	ND	01-09	6	6
10-26	6	6	12-03	7	6	01-10	6	6
10-27	6	6	12-04	7	6	01-11	ND	ND
10-28	6	6	12-05	7	6	01-12	ND	ND
10-29	6	6	12-06	7	6	01-13	6	6
10-30	6	6	12-07	7	7	01-14	6	6
10-31	6	6	12-08	7	6	01-15	6	6
11-01	6	6	12-09	7	6	01-16	6	6
11-02	6	6	12-10	7	6	01-17	6	6
11-03	6	6	12-11	7	6	01-18	6	ND
11-04	6	6	12-12	7	6	01-19	6	ND
11-05	6	6	12-13	7	6	01-20	6	ND
11-06	6	6	12-14	7	6	01-21	6	ND
11-07	6	6	12-15	7	6			

be negative. It is possible that rhodamine WT was present in extremely low concentrations; however, when very low concentrations of dye are present, it is difficult to distinguish the dye fluorescence from background fluorescence. The fluorometer dial readings for the nine monitoring points are shown in table A-3.

Estimated ground-water velocities ranged from 30 to 130 ft/d. Estimated ground-water-flow velocity to site C1 is 120 to 130 ft/d, site C6 is 30 ft/d, site C7 is 50 ft/d, site C8 is 70 to 75 ft/d, and site C9 is 110 to 120 ft/d. Although dye was detected at sites C3 and C4, which are spring-fed streams, these sites were not used to determine direction of ground-water flow because it was not possible to determine the upstream point or points of resurgence.

Table A-3.--Fluorometric data for the passive detectors from dye-tracer test C near Rippon, West Virginia

[** indicates primary dye recovery, ## indicates secondary dye recovery, ND indicates no data available]

Tracer-test C - Rhodamine WT injected on 02-19-1988

Date	Spring site C1	Spring site C2	Stream site C3	Stream site C4	Spring site C5	Spring site C6	Spring site C7	Spring site C8	Stream site C9
02-26	5	4	6	7	4	4	3	ND	ND
03-04	5	3	4	6	4	5	3	4	ND
03-11	6	5	7	4	6	5	4	4	ND
03-17	5	6	7	8	4	5	3	7	ND
03-25	6	6	7	5	4	5	3	5	ND
04-01	5	5	9	8	4	5	4	6	ND
04-08	5	5	10	6	4	4	4	6	ND
04-15	6	4	8	10	4	5	4	7	ND
04-22	5	4	10	5	4	4	4	4	8
04-29	6	6	8	10	4	5	4	6	7
05-06	4	4	6	7	5	4	4	7	10
05-13	7	6	13	10	5	5	4	8	12
05-20	6	4	12	10	5	5	4	8	5
05-27	8	8	ND	10	6	4	6**	6	12
06-03	6	5	9	10	5	4	4	8	9
06-10	6	5	10	6	5	6	5	7	7
06-17	9**	7	9	13**	6	4	6##	11**	19**
06-24	10	7	15**	14	6	9**	4	15	17
07-01	11	6	13	20	5	4	4	6	15
07-08	8	7	12	24	5	7	4	9	21
Detection	Positive	Negative	Positive	Positive	Negative	Positive	Positive	Positive	Positive

Tracer test D began on April 7, 1988, and ended on October 14, 1988. One and a quarter gallons of rhodamine WT was injected into a sinkhole near Shenandoah Junction; seven expected dye resurgence points were monitored with passive detectors (fig. A-4). Dye was detected at site D7 within 2 weeks. Within 12 to 20 weeks, dye was detected at sites D1, D2, D3, D4, and D6. Site D5 showed only minute variations above background fluorescence; therefore, dye detection at the site was considered to be negative. The fluorometer dial readings for the seven sites are presented in table A-4.

Estimated ground-water velocities to sites D1, D2, and D4 ranged from 150 to 185 ft/d. Estimated ground-water-flow velocity to site D1 is 155 to 170 ft/d, site D2 is 155 to 180 ft/d, and site D4 is 150 to 185 ft/d. The estimated ground-water-flow velocity to site D7 is at least 840 ft/d. Sites D3 and D6 are surface-water sites, and were not used to estimate ground-water flow direction or velocity because it was not possible to determine the upstream point or points of resurgence.

Site D7 is located at the junction of several large faults. One mapped fault extends from an area near site D-7 to within 2 miles of the injection point. A straight-line extension of this fault would bring it very close to the injection site. Solutional enlargement of fractures along this fault could have created a conduit between the injection site and site D-7, which might account for the rapid movement of the dye to site D-7.

Table A-4.--Fluorometric data for the passive detectors from dye-tracer test D near Shenandoah Junction, West Virginia

[** indicates primary dye recovery, ## indicates secondary dye recovery, ND indicates no data available]

	Tracer test D - Rhodamine WT injected 04-07-1988						
Date	Spring site D1	Spring site D2	Stream site D3	Spring site D4	Spring site D5	Stream site D6	Stream site D7
04-22	5	6	7	13	5	ND	111**
05-06	5	5	6	14	5	5	99
05-20	5	5	6	17	4	8	31
06-03	6	7	5	14	5	8	18
06-17	5	5	6	12	5	7	28
07-01	6	5	11**	30**	5	9	27
07-15	6	8**	15	33	4	11**	16
07-29	5	6	19	ND	5	ND	16
08-12	ND	8	17	ND	4	14	12
08-26	8**	8	18	ND	4	25	11
09-09	9	8	22	12	4	20	14
09-23	5	6	20	15	4	14	10
10-07	5	5	8	6	4	9	4
10-21	4	5	6	7	4	5	5
11-03	6	5	7	6	ND	11	7
Detection	Positive	Positive	Positive	Positive	Negative	Positive	Positive

Tracer test E began on November 9, 1988, and ended on March 14, 1989. Approximately 1 pound of fluorescein was injected into a sinkhole near Summit Point; and five expected dye-resurgence points were monitored with passive detectors (fig. A-5). In addition, daily water samples were collected at site E5, from the date of injection.

Here again, as in tracer test B, the fluctuations in background fluorescence were so pronounced that fluorometric and visual analysis was ineffective at determining the presence of low concentrations of dye. Although dye may have been present at several resurgence points, absolute detection of the dye was not possible and the results of the fluorescein traces are considered inconclusive.

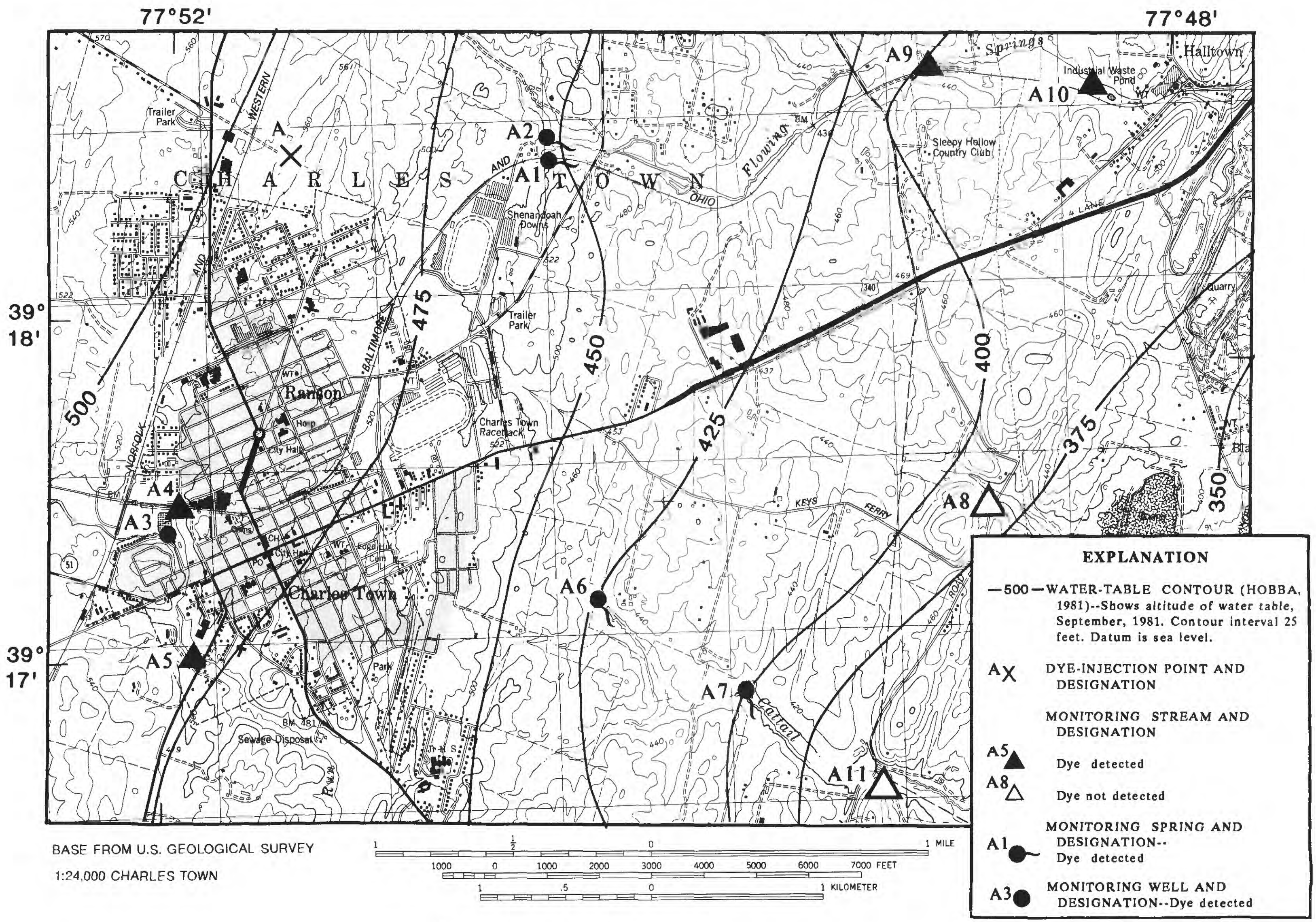

Figure A-1.-- Location of injection and monitoring points for dye-tracer test A north of Ranson, West Virginia.

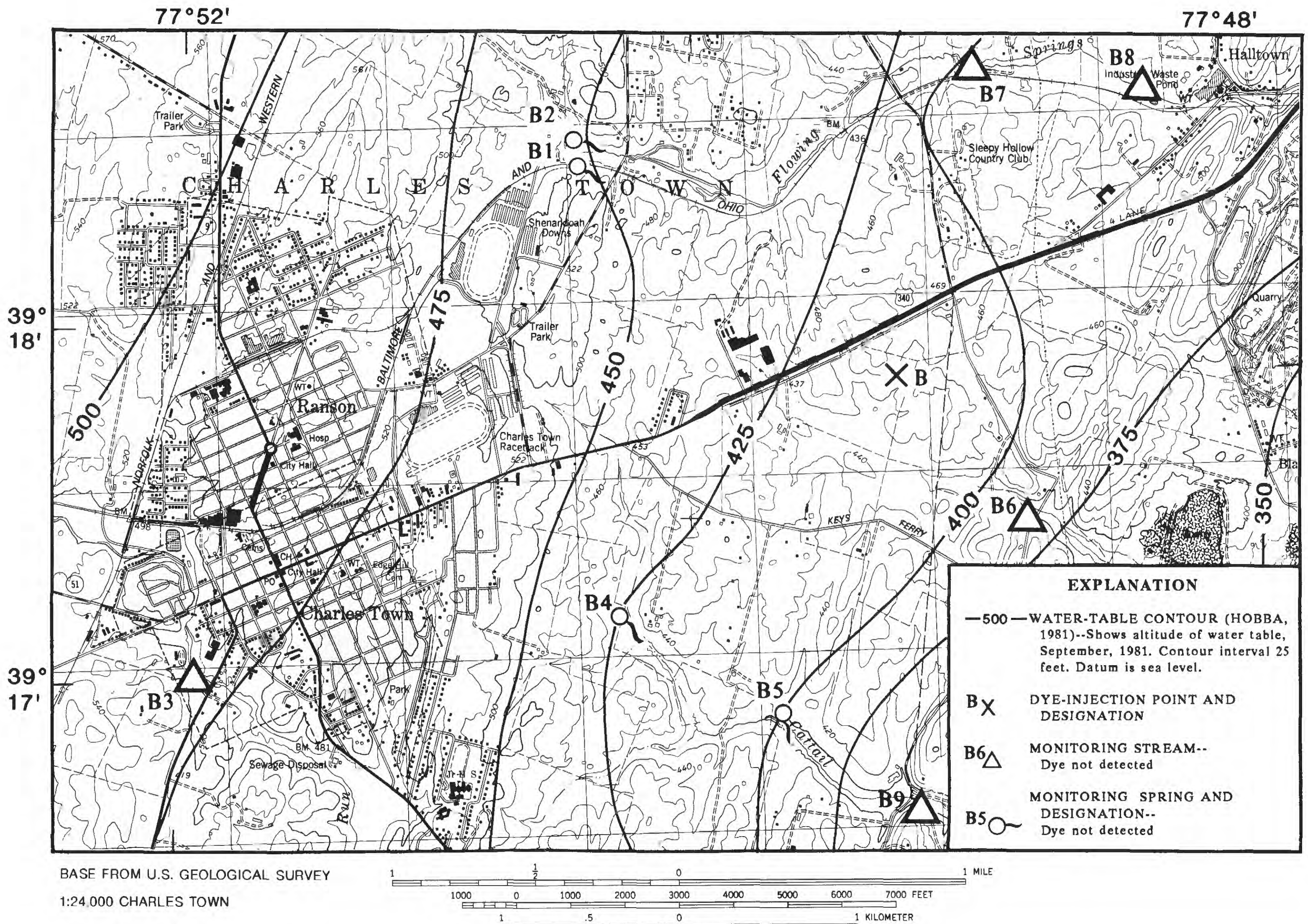

Figure A-2.-- Location of injection and monitoring points for dye-tracer test B east of Charles Town, West Virginia.

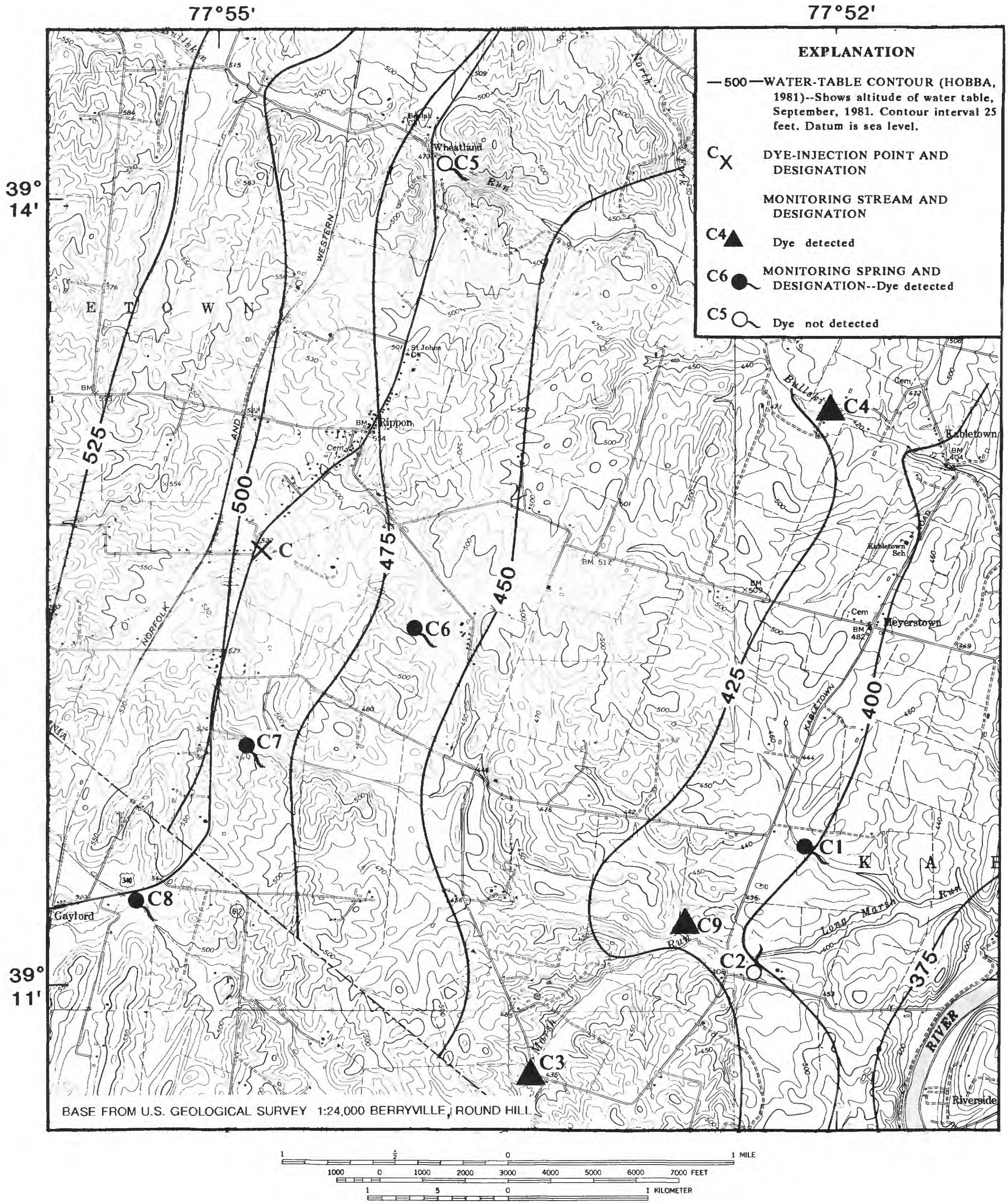

Figure A-3.-- Location of injection and monitoring points for dye-tracer test C near Rippon, West Virginia.

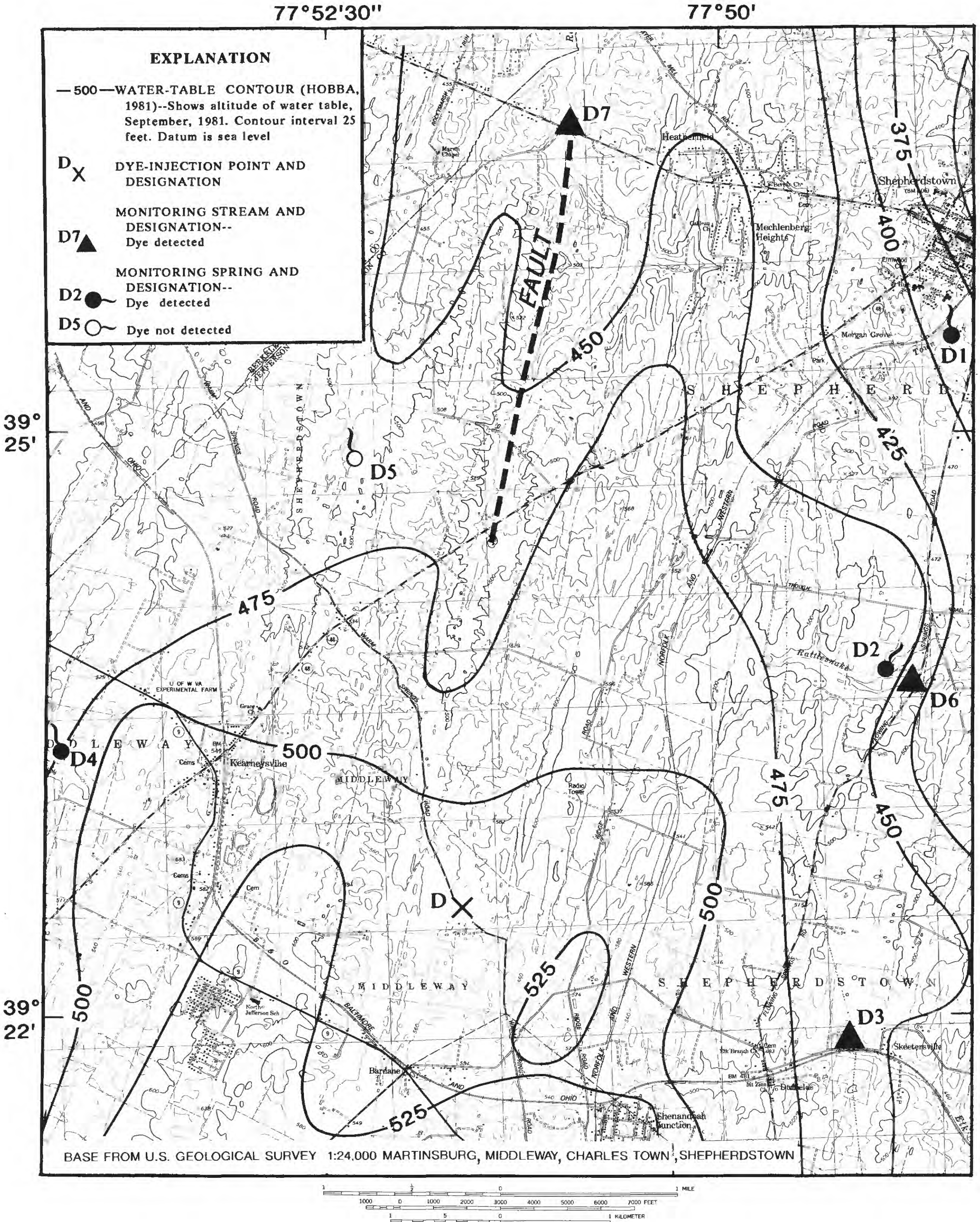

Figure A-4.-- Location of injection and monitoring points for dye-tracer test D near Shenandoah Junction, West Virginia.

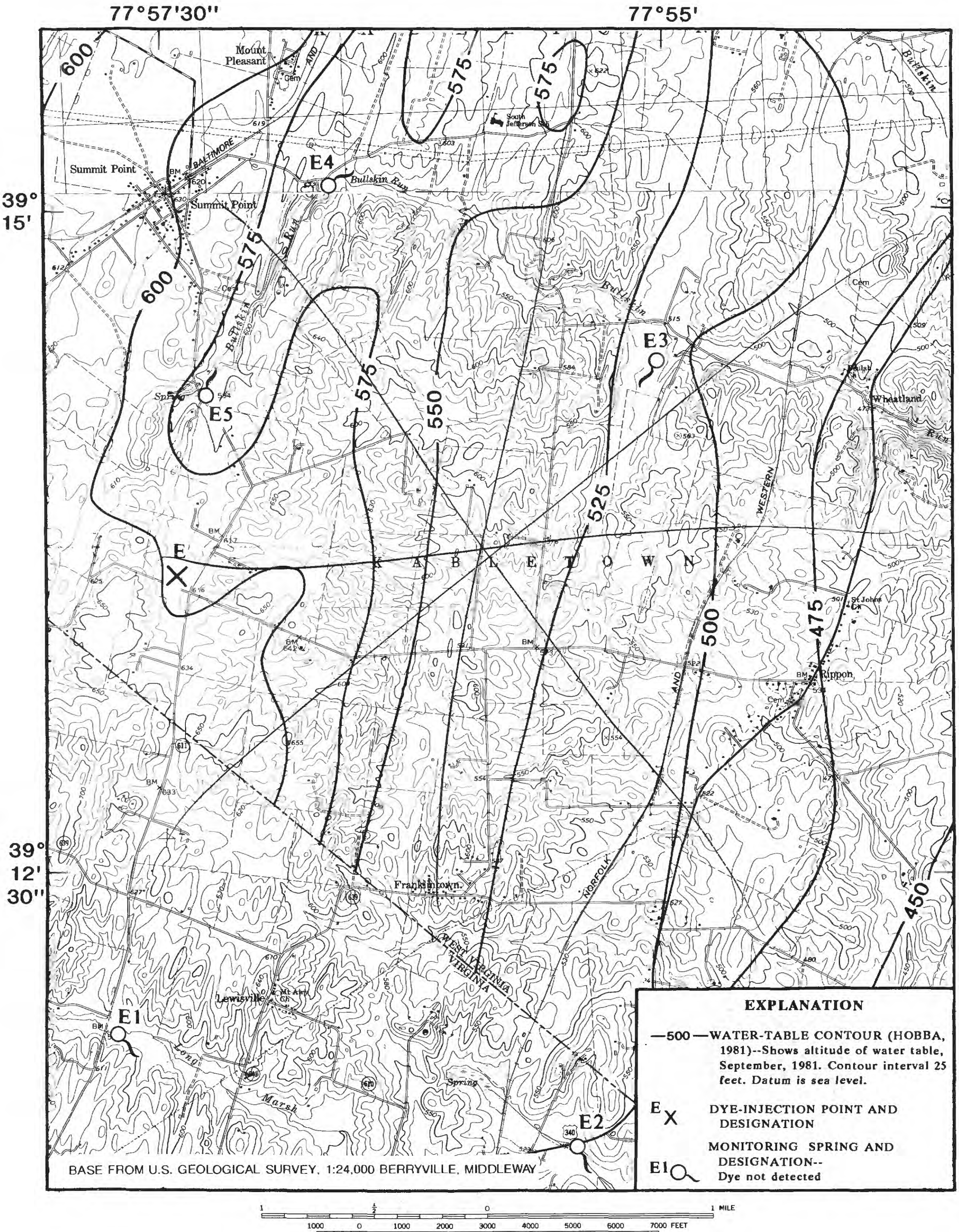

Figure A-5.-- Location of injection and monitoring points for dye-tracer test E near Summit Point, West Virginia.

APPENDIX B

Analytical Data

Appendix B-1.--Ground-water chemical analyses for July 1988

STATION NAME	Latitude	Longitude	Hydro-logic unit code	Geo-logic unit	Date	Temper-ature, water (deg C)
03 C MARCUM JR.	39 10 35 N	077 50 14 W	02070007	377CHLH	07-25-88	15.0
16 J LOUTHAN	39 11 18 N	077 54 24 W	02070007	374ELBK	07-25-88	15.0
22 D N HOOVER	39 12 00 N	077 52 03 W	02070007	374ELBK	07-26-88	14.0
28 P B ROGERS	39 13 37 N	077 50 44 W	02070007	374ELBK	07-25-88	15.0
31 V BURNS	39 13 54 N	077 53 49 W	02070004	371CCCG	07-26-88	16.0
32 A M MORGAN	39 13 28 N	077 54 31 W	02070007	371CCCG	07-26-88	15.0
33 H LLOYD	39 13 25 N	077 55 26 W	02070007	367BKMN	07-26-88	15.0
34 HARRY ATHEY	39 13 47 N	077 57 20 W	02070007	367BKMN	07-26-88	13.0
35 C VIANDS JR	39 14 36 N	077 46 57 W	02070007	377CHLH	07-25-88	12.5
42 W MICKEY	39 14 49 N	077 53 14 W	02070007	371CCCG	07-26-88	23.0
43 H N RANDOLPH	39 14 18 N	077 55 41 W	02070007	371CCCG	07-26-88	14.0
54 CLIPP SPRING	39 15 05 N	077 50 25 W	02070007	374ELBK	07-25-88	12.5
63 RANDOLPH BURCH	39 15 20 N	078 00 08 W	02070004	367BKMN	07-29-88	13.5
65 NORMAN FOSTER	39 16 57 N	077 45 48 W	02070007	377CHLH	07-29-88	14.0
69 LW LLOYD SR	39 16 27 N	077 50 55 W	02070007	374ELBK	07-28-88	15.0
70 ROLFE HAYES	39 16 02 N	077 51 41 W	02070007	374ELBK	07-28-88	16.5
71B W C PERRY	39 16 16 N	077 52 12 W	02070007	374ELBK	07-28-88	13.5
73 FRANK PAPIANO	39 16 57 N	077 53 48 W	02070007	371CCCG	07-27-88	14.0
88 LEO WIDMYER	39 17 24 N	077 49 04 W	02070007	374ELBK	07-27-88	14.0
88A CATTAIL SPRING	39 16 55 N	077 49 38 W	02070007	374ELBK	07-27-88	15.5
90 CHARLES TOWN RACE TRACK	39 17 52 N	077 51 03 W	02070007	374ELBK	07-27-88	14.0
91A CHARLES TOWN PS WELL PS-2	39 17 24 N	077 52 02 W	02070007	374ELBK	07-25-88	13.0
94 THOMAS MAGAHA	39 17 37 N	077 55 26 W	02070007	371CCCG	07-27-88	14.0
102 HAROLD STAUBS	39 18 02 N	077 45 05 W	02070007	377CHLH	07-26-88	13.5
106 C L ROBINSON	39 18 54 N	077 48 46 W	02070004	374ELBK	07-27-88	13.5
107 WP & CD CAIN	39 18 24 N	077 49 01 W	02070007	374ELBK	07-27-88	14.0
109 FLOWING SPRING (KANE)	39 18 40 N	077 50 40 W	02070007	371CCCG	07-25-88	13.0
111 WALTER LEMASTER	39 18 56 N	077 52 19 W	02070007	371CCCG	07-29-88	13.5
116 VICTOR BLUE	39 18 44 N	077 57 09 W	02070004	367BKMN	07-27-88	16.0
126 RODERICK BROS	39 19 52 N	077 49 56 W	02070004	371CCCG	07-26-88	14.0
139 HARPERS FERRY P S SPRING	39 20 10 N	077 45 52 W	02070007	377TMSN	07-26-88	12.0
144 FRANK W BUCKLES	39 20 37 N	077 50 56 W	02070004	371CCCG	07-28-88	13.5
146 W O LLOYD	39 20 19 N	077 52 09 W	02070007	371CCCG	07-28-88	12.5
156 KENNETH WILT	39 21 28 N	077 46 29 W	02070004	377WSBR	07-26-88	13.5
160 PAUL CHAPMAN	39 21 17 N	077 50 29 W	02070004	371CCCG	07-28-88	15.0
176 HOLLIS-LOWMAN	39 22 43 N	077 53 35 W	02070004	367BKMN	07-28-88	12.5
180 R W SEIDERS	39 23 52 N	077 44 33 W	00000000	377TMSN	07-27-88	14.0
182 S J DONLEY JR	39 23 38 N	077 45 05 W	02070004	377WSBR	07-27-88	14.0
198 FORREST HAMMOND	39 24 48 N	077 52 41 W	02070004	371CCCG	07-28-88	14.0
205 F W GATES	39 25 41 N	077 50 16 W	02070004	371CCCG	07-28-88	13.5

Appendix B-1.--Ground-water chemical analyses for July 1988--Continued

Station name	Bicarbonate, water WH IT field (mg/L as HCO_3)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrate, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorous ortho, dissolved (mg/L as P)	Hardness, total (mg/L as $CaCO_3$)
03 C MARCUM JR.	18	<0.01	<0.01	7.5	7.5	0.12	45
16 J LOUTHAN	370	<.01	<.01	12	12	<.01	400
22 D N HOOVER	320	.01	<.01	16	16	<.01	330
28 P B ROGERS	350	<.01	<.01	0.24	0.24	<.01	320
31 V BURNS	530	.04	<.01	25	25	<.01	580
32 A M MORGAN	340	<.01	<.01	15	15	.01	340
33 H LLOYD	260	.04	<.01	6.2	6.2	<.01	250
34 HARRY ATHEY	390	.03	<.01	19	19	.01	410
35 C VIANDS JR	46	<.01	<.01	<.10	<.10	.05	30
42 W MICKEY	380	.02	<.01	9.5	9.5	<.01	400
43 H N RANDOLPH	360	.04	<.01	13	13	<.01	680
54 CLIPP SPRING	290	<.01	<.01	7.9	7.9	<.01	290
63 RANDOLPH BURCH	390	.02	<.01	14	14	.01	380
65 NORMAN FOSTER	118	<.01	<.01	.10	.11	.05	82
69 LW LLOYD SR	330	.02	<.01	4.5	4.5	<.01	300
70 ROLFE HAYES	350	<.01	<.01	3.4	3.4	<.01	330
71B W C PERRY	290	.02	<.01	30	30	<.01	380
73 FRANK PAPIANO	370	.03	<.01	5.1	5.1	.01	320
88 LEO WIDMYER	300	.02	<.01	19	19	<.01	380
88A CATTAIL SPRING	300	.02	<.01	4.7	4.7	<.01	300
90 CHARLES TOWN RACE TRACK	340	.06	<.01	3.3	3.3	<.01	650
91A CHARLES TOWN PS WELL PS-2	290	<.01	<.01	7.3	7.3	<.01	290
94 THOMAS MAGAHA	370	.04	<.01	12	12	<.01	360
102 HAROLD STAUBS	35	<.01	<.01	4.6	4.6	.03	56
106 C L ROBINSON	380	.01	<.01	3.6	3.6	<.01	350
107 WP & CD CAIN	420	.01	<.01	4.1	4.1	<.01	410
109 FLOWING SPRING (KANE)	350	.01	<.01	5.9	5.9	.01	330
116 VICTOR BLUE	390	.05	<.01	11	11	.04	400
111 WALTER LEMASTER	390	.23	.09	8.2	8.3	.15	350
126 RODERICK BROS	370	.17	.03	1.5	1.5	<.01	340
139 HARPERS FERRY P S SPRING	340	.03	<.01	4.0	4.0	.01	320
144 FRANK W BUCKLES	340	.01	<.01	12	12	.02	350
146 W O LLOYD	310	.03	<.01	15	15	.31	320
156 KENNETH WILT	330	<.01	<.01	6.6	6.6	.01	330
160 PAUL CHAPMAN	460	.23	1.1	.80	1.9	<.01	360
176 HOLLIS-LOWMAN	320	<.01	<.01	5.3	5.3	<.01	270
180 R W SEIDERS	480	.02	.02	20	20	.01	510
182 S J DONLEY JR	450	7.7	<.01	63	63	.01	650
198 FORREST HAMMOND	220	<.01	<.01	6.7	6.7	.01	200
205 F W GATES	350	<.01	<.01	1.2	1.2	<.01	290

Appendix B-1.--Ground-water chemical analyses for July 1988--Continued

Station name	Barometric pressure (mm of Hg)	Specific conductance (uS/cm)	Oxygen, dissolved (mg/L)	pH (standard units)	Alkalinity, wat wh tot it field (mg/L as $CaCO_3$)	Carbonate, water wh it field (mg/L as CO_3)
03 C MARCUM JR.	738	144	6.5	5.9	15	0
16 J LOUTHAN	748	740	6.2	7.0	300	0
22 D N HOOVER	744	650	5.8	7.2	265	0
28 P B ROGERS	750	625	1.4	7.2	290	0
31 V BURNS	747	1200	1.1	6.7	435	0
32 A M MORGAN	747	700	8.3	6.8	280	0
33 H LLOYD	746	440	8.6	7.0	210	0
34 HARRY ATHEY	744	850	0.7	6.8	320	0
35 C VIANDS JR	743	89	5.8	6.3	38	0
42 W MICKEY	749	700	7.1	7.1	315	0
43 H N RANDOLPH	745	1550	1.0	6.8	295	0
54 CLIPP SPRING	751	--	6.6	7.2	239	0
63 RANDOLPH BURCH	745	765	8.0	7.2	318	0
65 NORMAN FOSTER	747	197	0.9	7.3	97	0
69 LW LLOYD SR	751	640	1.4	7.2	270	0
70 ROLFE HAYES	751	645	0.8	7.3	288	0
71B W C PERRY	751	840	1.0	7.3	234	0
73 FRANK PAPIANO	746	640	0.8	6.9	305	0
88 LEO WIDMYER	752	840	8.7	7.2	243	0
88A CATTAIL SPRING	754	625	5.8	7.3	242	0
90 CHARLES TOWN RACE TRACK	--	1040	3.7	7.3	275	0
91A CHARLES TOWN PS WELL PS-2	--	554	5.5	7.4	234	0
94 THOMAS MAGAHA	748	670	0.6	6.9	305	0
102 HAROLD STAUBS	740	185	6.5	5.9	29	0
106 C L ROBINSON	--	750	1.3	7.4	312	0
107 WP & CD CAIN	751	830	8.0	7.4	341	0
109 FLOWING SPRING (KANE)	750	640	4.2	7.2	284	0
111 WALTER LEMASTER	751	910	2.0	7.2	320	0
116 VICTOR BLUE	749	825	0.6	6.9	320	0
126 RODERICK BROS	746	635	1.2	7.5	300	0
139 HARPERS FERRY P S SPRING	--	520	7.2	7.2	282	0
144 FRANK W BUCKLES	749	790	0.9	7.3	280	0
146 W O LLOYD	--	750	0.6	7.3	256	0
156 KENNETH WILT	--	560	8.8	7.2	270	0
160 PAUL CHAPMAN	750	1000	0.3	7.1	375	0
176 HOLLIS-LOWMAN	746	550	7.3	7.0	265	0
180 R W SEIDERS	748	1010	5.9	7.1	390	0
182 S J DONLEY JR	747	1300	1.8	6.8	370	0
198 FORREST HAMMOND	746	395	7.2	7.3	184	0
205 F W GATES	749	580	7.2	7.2	290	0

Appendix B-1.--Ground-water chemical analyses for July 1988--Continued

Station name	Hardness, noncarb wh wat tot fld (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)
03 C MARCUM JR.	31	10	4.9	5.5	3.1	6.7	12
16 J LOUTHAN	94	86	45	6.5	3.4	17	39
22 D N HOOVER	75	93	24	2.5	10	13	24
28 P B ROGERS	53	62	41	1.2	1.8	4.2	46
31 V BURNS	140	140	57	7.1	8.0	46	34
32 A M MORGAN	40	110	15	5.8	2.1	12	7.7
33 H LLOYD	52	92	5.2	1.9	0.80	5.4	10
34 HARRY ATHEY	110	150	8.0	9.9	6.6	21	28
35 C VIANDS JR	0	5.7	3.8	7.3	0.50	1.3	5.2
42 W MICKEY	400	110	30	7.3	4.2	16	35
43 H N RANDOLPH	460	210	37	68	11	270	140
54 CLIPP SPRING	66	75	24	4.0	2.5	10	26
63 RANDOLPH BURCH	78	100	32	5.1	1.8	18	24
65 NORMAN FOSTER	0	26	4.2	8.5	0.40	2.2	9.0
69 LW LLOYD SR	300	87	20	13	3.1	10	33
70 ROLFE HAYES	130	83	30	3.7	2.8	6.6	28
71B W C PERRY	380	100	31	4.1	6.4	22	27
73 FRANK PAPIANO	320	120	5.6	27	1.6	40	10
88 LEO WIDMYER	130	92	36	4.4	7.0	33	39
88A CATTAIL SPRING	44	81	23	5.8	2.6	12	28
90 CHARLES TOWN RACE TRACK	450	180	49	20	3.6	39	340
91A CHARLES TOWN PS WELL PS-2	49	89	17	6.6	3.0	15	20
94 THOMAS MAGAHA	360	130	8.7	6.1	10	16	16
102 HAROLD STAUBS	24	12	6.4	11	1.2	19	5.9
106 C L ROBINSON	46	89	30	5.4	18	11	48
107 WP & CD CAIN	120	110	32	6.5	2.3	10	34
109 FLOWING SPRING (KANE)	120	97	22	18	6.0	35	30
111 WALTER LEMASTER	37	110	19	10	11	9.0	45
116 VICTOR BLUE	84	120	25	8.8	4.8	33	43
126 RODERICK BROS	91	75	38	9.0	3.2	12	45
139 HARPERS FERRY P S SPRING	93	96	20	3.0	1.4	6.9	27
144 FRANK W BUCKLES	100	90	31	5.0	9.3	7.7	41
146 W O LLOYD	58	100	16	5.6	10	18	13
156 KENNETH WILT	110	88	26	5.5	3.6	11	37
160 PAUL CHAPMAN	0	88	33	32	8.0	47	52
176 HOLLIS-LOWMAN	79	98	7.2	1.7	1.9	4.5	10
180 R W SEIDERS	120	140	38	23	2.1	41	48
182 S J DONLEY JR	370	160	60	12	12	62	41
198 FORREST HAMMOND	28	72	3.7	1.8	1.6	4.6	7.5
205 F W GATES	36	71	27	2.9	7.0	3.2	34

Appendix B-1.--Ground-water chemical analyses for July 1988--Continued

Station name	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Arsenic, dissolved (ug/L as As)	Iron, dissolved (ug/L as Fe)	Manganese, dissolved (ug/L as Mn)	Coliform, fecal, 0.7 UM-MF (Cols./100 mL)
03 C MARCUM JR.	0.20	22	--	6	14	60
16 J LOUTHAN	.70	11	--	10	1	<1
22 D N HOOVER	.40	10	<1	12	2	K3
28 P B ROGERS	.30	11	--	18	<1	<1
31 V BURNS	.30	15	--	10	68	K2
32 A M MORGAN	.30	15	<1	5	<1	<1
33 H LLOYD	.20	10	--	15	3	<1
34 HARRY ATHEY	.10	12	--	14	<1	<1
35 C VIANDS JR	<.10	22	--	44	12	22
42 W MICKEY	.40	11	--	11	2	K4
43 H N RANDOLPH	.30	16	--	11	<1	<1
54 CLIPP SPRING	.30	10	--	10	<1	400
63 RANDOLPH BURCH	.20	7.2	--	10	1	<1
65 NORMAN FOSTER	.30	27	--	56	400	<1
69 LW LLOYD SR	.20	13	--	8	<1	230
70 ROLFE HAYES	.20	11	--	<3	<1	<1
71B W C PERRY	.20	10	--	3	<1	<1
73 FRANK PAPIANO	.10	12	--	5	<1	<1
88 LEO WIDMYER	.30	10	--	9	<1	K4400
88A CATTAIL SPRING	.20	11	--	15	19	120
90 CHARLES TOWN RACE TRACK	.30	15	<1	430	610	K2
91A CHARLES TOWN PS WELL PS-2	.30	11	<1	12	3	55
94 THOMAS MAGAHA	.10	12	--	<3	<1	80
102 HAROLD STAUBS	.20	19	--	15	6	<1
106 C L ROBINSON	.60	12	--	12	23	K10
107 WP & CD CAIN	.30	14	--	5	<1	<1
109 FLOWING SPRING (KANE)	.20	11	<1	16	4	K2000
116 VICTOR BLUE	<.10	7.8	--	5	2	K2
111 WALTER LEMASTER	.30	15	--	8	26	<80
126 RODERICK BROS	.90	11	--	82	36	<1
139 HARPERS FERRY P S SPRING	.40	11	--	11	1	<1
144 FRANK W BUCKLES	.40	11	--	4	1	<1
146 W O LLOYD	.20	14	--	4	2	K5
156 KENNETH WILT	.30	12	--	12	<1	<1
160 PAUL CHAPMAN	.40	13	--	14	100	24
176 HOLLIS-LOWMAN	.20	12	--	14	<1	K1
180 R W SEIDERS	.30	12	--	9	1	K1
182 S J DONLEY JR	.20	15	--	10	300	110
198 FORREST HAMMOND	.10	9.2	--	12	<1	K14
205 F W GATES	.40	11	--	11	<1	<1

Appendix B-1.--Ground-water chemical analyses for July 1988--Continued

STATION NAME	Strep-tococci fecal, KF agar (Cols. per 100 mL)	Solids, residue at 180 deg. C dis-solved (mg/L)	Solids, sum of consti-tuents, dis-solved (mg/L)	Nitro-gen, ammonia, dis-solved (mg/L as NH_4)	Nitro-gen, Nitrate dis-solved (mg/L as NO_3)	Depth of well, total (feet)	Radon 222, total (pCi/L)
03 C MARCUM JR.	<1	107	106	--	33	348	2300
16 J LOUTHAN	K1	345	445	--	53	70	--
22 D N HOOVER	62	402	401	0.01	71	190	--
28 P B ROGERS	K1	345	331	--	1.1	280	--
31 V BURNS	--	730	686	.05	110	160	--
32 A M MORGAN	<1	412	412	--	66	158	--
33 H LLOYD	K13	258	273	.05	27	122	--
34 HARRY ATHEY	K430	577	499	.04	84	85	--
35 C VIANDS JR	K6	65	70	--	<0.44	210	8700
42 W MICKEY	K4	386	256	.03	42	100	--
43 H N RANDOLPH	<1	1230	939	.05	58	65	--
54 CLIPP SPRING	K850	334	318	--	35	--	--
63 RANDOLPH BURCH	2300	447	432	.03	62	144	--
65 NORMAN FOSTER	<1	126	133	--	.44	200	--
69 LW LLOYD SR	63	365	199	.03	20	43	--
70 ROLFE HAYES	<1	355	301	--	15	66	--
71B W C PERRY	K1	465	333	.03	130	200	--
73 FRANK PAPIANO	120	423	239	.04	23	100	--
88 LEO WIDMYER	K880	455	452	.03	84	80	--
88A CATTAIL SPRING	270	336	336	.03	21	--	--
90 CHARLES TOWN RACE TRACK	K4	875	786	.08	15	--	--
91A CHARLES TOWN PS WELL PS-2	43	337	340	--	32	--	--
94 THOMAS MAGAHA	97	455	252	.05	53	146	--
102 HAROLD STAUBS	70	132	114	--	20	125	3100
106 C L ROBINSON	23	425	410	.01	16	93	--
107 WP & CD CAIN	K8	428	397	.01	18	230	--
109 FLOWING SPRING (KANE)	K840	417	374	.01	26	--	--
111 WALTER LEMASTER	K6000	491	446	.30	36	21	--
116 VICTOR BLUE	48	494	482	.06	49	170	--
126 RODERICK BROS	K1	386	353	.22	6.5	37	--
139 HARPERS FERRY P S SPRING	<1	366	321	.04	18	--	--
144 FRANK W BUCKLES	K2	411	399	.01	53	83	--
146 W O LLOYD	K14	396	398	.04	66	--	--
156 KENNETH WILT	<1	393	343	--	29	120	--
160 PAUL CHAPMAN	99	431	509	.30	3.5	39	--
176 HOLLIS-LOWMAN	<2	302	276	--	23	65	--
180 R W SEIDERS	K3	607	625	.03	89	285	--
182 S J DONLEY JR	K1600	895	818	9.9	280	111	--
198 FORREST HAMMOND	36	242	230	--	30	90	--
205 F W GATES	<1	327	313	--	5.3	160	--

Appendix B-1.--Ground-water chemical analyses for July 1988--Continued

Station name	Latitude	Longitude	Hydro-logic unit code	Geo-logic unit	Date	Temper-ature, water (deg C)
209 MILLARD MILLS	39 26 18 N	077 51 24 W	02070004	371CCCG	07-28-88	15.5
213 J C DAY	39 28 43 N	077 48 54 W	02070004	371CCCG	07-27-88	13.5
230 RESEARCH INSTITUTE SPRING	39 25 10 N	077 48 40 W	02070004	371CCCG	07-26-88	12.5
231 FRANK HILL JR	39 24 57 N	077 50 12 W	02070004	371CCCG	07-26-88	14.5
232 HARPERS FERRY JOB CORPS	39 20 45 N	077 48 44 W	02070004	374ELBK	07-26-88	13.0
233 WILLIAM JOHNSON	39 27 43 N	077 48 10 W	02070004	371CCCG	07-27-88	14.5
234 ROMANO	39 25 30 N	077 51 51 W	02070004	367BKMN	07-28-88	13.5
235 KNODE	39 24 32 N	077 51 42 W	02070004	371CCCG	07-28-88	13.5
237 HENRY WILLARD JR.	39 24 33 N	077 45 12 W	02070004	374ELBK	07-27-88	13.5
238 FRED DONLEY	39 23 44 N	077 45 53 W	02070004	374ELBK	07-27-88	14.5
239 HS LINK	39 23 27 N	077 50 42 W	02070004	371CCCG	07-28-88	13.5
240 PATTY JENKINS	39 22 19 N	077 56 05 W	02070004	361MRBG	07-28-88	16.0
241 HUGHES	39 20 26 N	077 57 01 W	02070007	361MRBG	08-04-88	13.5
242 ROBERT TABB	39 19 47 N	077 55 08 W	02070007	367BKMN	07-27-88	15.0
243 ANIMAL WELFARE SOCIETY	39 20 02 N	077 54 37 W	02070004	371CCCG	07-28-88	15.0
244 HOWARD ROPER	39 20 32 N	077 53 04 W	02070004	367BKMN	07-28-88	15.0
246 DON FOWLER	39 17 30 N	078 00 00 W	02070004	367BKMN	07-27-88	--
247 GLENN JENKINS	39 17 54 N	077 57 09 W	02070004	367BKMN	07-27-88	13.0
248 JAMES MILTON	39 16 57 N	077 52 45 W	02070007	371CCCG	07-28-88	19.0
249 REBECCA WHIPP	39 17 27 N	077 47 18 W	02070007	377TMSN	07-26-88	13.0
250 STANLEY DUNN	39 18 15 N	077 52 59 W	02070004	371CCCG	07-28-88	15.0
251 CRIM	39 15 32 N	077 56 27 W	02070004	367BKMN	07-28-88	14.0
252 HEAD SPRING	39 14 13 N	077 57 23 W	02070007	371CCCG	07-29-88	14.0
253 EISNER WELL	39 14 13 N	077 57 29 W	02070007	367BKMN	07-29-88	14.0
254 WP MILLS	39 12 17 N	077 56 06 W	02070007	371CCCG	07-25-88	16.0
258 BUTLER WELL	39 13 32 N	077 48 47 W	02070007	374ELBK	07-27-88	15.0
259 JAMES FAUST	39 13 35 N	077 48 32 W	02070007	377CHLH	07-26-88	15.0
260 PARKVIEW/WOODLAND MHP	39 19 56 N	077 51 17 W	02070007	371CCCG	07-29-88	15.0
261 GREY SPRING	39 23 43 N	077 48 54 W	02070004	367BKMN	07-26-88	14.5
270 LOUTHAN SPRING	39 11 53 N	077 54 50 W	02070007	371CCCG	07-29-88	12.5

Appendix B-1.--Ground-water chemical analyses for July 1988--Continued

STATION NAME	Barometric pressure (mm of Hg)	Specific conductance (uS/cm)	Oxygen, dissolved (mg/L)	pH (standard units)	Alkalinity, wat wh tot it field (mg/L as $CaCO_3$)	Carbonate, water wh it field (mg/L as CO_3)
209 MILLARD MILLS	748	675	6.4	7.0	300	0
213 J C DAY	747	850	2.2	7.2	315	0
230 RESEARCH INSTITUTE SPRING	745	568	8.0	7.1	243	0
231 FRANK HILL JR	742	1110	5.6	7.2	330	0
232 HARPERS FERRY JOB CORPS	746	510	9.4	7.6	266	0
233 WILLIAM JOHNSON	748	455	9.1	7.3	230	0
234 ROMANO	748	583	2.3	7.1	270	0
235 KNODE	745	570	8.3	7.2	265	0
237 HENRY WILLARD JR.	747	845	5.2	7.4	285	0
238 FRED DONLEY	748	760	8.4	7.1	324	0
239 HS LINK	744	695	1.1	7.3	303	0
240 PATTY JENKINS	751	290	0.3	7.5	140	0
241 HUGHES	752	1400	1.0	6.9	238	0
242 ROBERT TABB	748	700	0.8	6.8	340	0
243 ANIMAL WELFARE SOCIETY	749	560	0.8	7.0	285	0
244 HOWARD ROPER	749	540	0.9	7.1	280	0
246 DON FOWLER	750	420	9.6	7.6	168	0
247 GLENN JENKINS	749	600	0.7	6.9	330	0
248 JAMES MILTON	749	640	0.7	7.0	245	0
249 REBECCA WHIPP	--	650	2.7	7.2	340	0
250 STANLEY DUNN	750	--	0.9	7.1	435	0
251 CRIM	746	550	0.9	6.7	270	0
252 HEAD SPRING	750	460	6.0	7.0	225	0
253 EISNER WELL	750	440	6.0	7.4	230	0
254 WP MILLS	747	720	8.4	6.8	330	0
258 BUTLER WELL	--	590	8.2	7.4	237	0
259 JAMES FAUST	744	270	2.2	7.9	89	0
260 PARKVIEW/WOODLAND MHP	751	700	6.4	7.5	315	0
261 GREY SPRING	744	565	7.7	7.0	255	0
270 LOUTHAN SPRING	--	630	8.8	7.5	252	0

Appendix B-1.--Ground-water chemical analyses for July 1988--Continued

STATION NAME	Bicarbonate, water wh it field (mg/L as HCO_3)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrate, dissolved (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorous, ortho, dissolved (mg/L as P)	Hardness, total (mg/L as $CaCO_3$)
209 MILLARD MILLS	370	0.02	<0.01	5.0	5.0	0.48	340
213 J C DAY	380	.02	<.01	12	12	<.01	410
230 RESEARCH INSTITUTE SPRING	300	.01	<.01	6.4	6.4	<.01	270
231 FRANK HILL JR	400	.02	<.01	0.44	0.44	<.01	420
232 HARPERS FERRY JOB CORPS	320	.04	<.01	3.5	3.5	<.01	330
233 WILLIAM JOHNSON	280	<.01	<.01	1.9	1.9	<.01	240
234 ROMANO	330	<.01	<.01	2.2	2.2	<.01	310
235 KNODE	325	.04	<.01	2.7	2.7	.29	280
237 HENRY WILLARD JR.	350	.01	.01	6.1	6.1	.01	390
238 FRED DONLEY	400	.05	.02	10	10	.01	400
239 HS LINK	370	<.01	.03	.47	.50	<.01	360
240 PATTY JENKINS	170	.03	.01	.48	.49	.04	140
241 HUGHES	290	.15	<.01	<.10	<.10	.02	680
242 ROBERT TABB	420	.03	<.01	5.6	5.6	<.01	400
243 ANIMAL WELFARE SOCIETY	350	.01	<.01	8.2	8.2	<.01	310
244 HOWARD ROPER	340	.02	<.01	5.1	5.1	.29	310
246 DON FOWLER	210	<.01	<.01	2.7	2.7	.01	210
247 GLENN JENKINS	400	.02	<.01	.98	.98	<.01	350
248 JAMES MILTON	300	<.01	<.01	20	20	.29	360
249 REBECCA WHIPP	420	.02	<.01	2.2	2.2	<.01	390
250 STANLEY DUNN	530	.50	.01	23	23	.01	510
251 CRIM	330	.01	<.01	6.2	6.2	.29	310
252 HEAD SPRING	270	<.01	<.01	4.6	4.6	.01	250
253 EISNER WELL	280	<.01	<.01	4.4	4.4	.01	250
254 WP MILLS	400	.03	<.01	7.0	7.0	<.01	370
258 BUTLER WELL	290	<.01	<.01	6.6	6.6	<.01	280
259 JAMES FAUST	110	.01	.10	.42	.52	<.01	110
260 PARKVIEW/WOODLAND MHP	380	.05	<.01	5.5	5.5	.01	350
261 GREY SPRING	310	.01	<.01	>5.7	5.7	<.01	290
270 LOUTHAN SPRING	310	<.01	<.01	7.3	7.3	.33	280

Appendix B-1.--Ground-water chemical analyses for July 1988--Continued

Station name	Hardness, noncarb wh wat tot fld (mg/L as $CaCO_3$)	Calcium, dis- solved (mg/L as Ca)	Magnesium, dis- solved (mg/L as Mg)	Sodium, dis- solved (mg/L as Na)	Potassium, dis- solved (mg/L as K)	Chloride, dis- solved (mg/L as Cl)	Sulfate, dis- solved (mg/L as SO_4)
209 MILLARD MILLS	130	120	10	2.6	2.1	7.2	25
213 J C DAY	81	110	33	6.0	6.0	15	52
230 RESEARCH INSTITUTE SPRING	110	80	18	2.8	2.4	9.5	23
231 FRANK HILL JR	84	100	41	70	2.1	150	47
232 HARPERS FERRY JOB CORPS	65	76	33	12	1.9	40	14
233 WILLIAM JOHNSON	24	81	8.3	3.1	2.7	3.0	9.4
234 ROMANO	84	110	7.9	4.0	1.3	8.8	26
235 KNODE	46	100	7.8	2.2	1.3	5.8	19
237 HENRY WILLARD JR.	88	84	43	20	3.1	38	63
238 FRED DONLEY	66	95	40	3.2	1.9	11	27
239 HS LINK	70	86	35	4.8	1.8	12	61
240 PATTY JENKINS	13	43	8.2	6.5	0.50	1.6	27
241 HUGHES	440	210	37	25	0.70	15	490
242 ROBERT TABB	61	150	7.0	8.6	1.0	31	17
243 ANIMAL WELFARE SOCIETY	310	110	9.3	4.5	1.6	11	12
244 HOWARD ROPER	30	110	7.6	4.4	1.4	8.0	7.5
246 DON FOWLER	51	62	13	3.0	1.9	2.6	31
247 GLENN JENKINS	140	120	12	2.2	0.50	5.1	15
248 JAMES MILTON	110	92	31	5.6	5.9	26	19
249 REBECCA WHIPP	49	100	35	11	1.9	19	43
250 STANLEY DUNN	170	160	27	21	10	51	14
251 CRIM	42	110	8.6	5.9	2.8	11	11
252 HEAD SPRING	26	85	8.5	2.2	2.1	5.6	13
253 EISNER WELL	21	86	9.2	1.7	2.5	3.9	12
254 WP MILLS	32	130	10	9.7	7.0	16	34
258 BUTLER WELL	37	76	21	7.8	4.7	10	14
259 JAMES FAUST	35	34	6.5	8.5	1.2	4.8	45
260 PARKVIEW/WOODLAND MHP	89	88	31	9.4	2.1	21	18
261 GREY SPRING	38	94	13	3.2	2.5	8.5	22
270 LOUTHAN SPRING	41	93	11	5.5	2.3	13	15

Appendix B-1.--Ground-water chemical analyses for July 1988--Continued

STATION NAME	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Arsenic, dissolved (ug/L as As)	Iron, dissolved (ug/L as Fe)	Manganese, dissolved (ug/L as Mn)	Coliform, fecal, 0.7 UM-MF (Cols./100 mL)
209 MILLARD MILLS	0.20	12	--	7	1	K15
213 J C DAY	.20	13	--	9	<1	<1
230 RESEARCH INSTITUTE SPRING	.30	10	--	8	<1	K4
231 FRANK HILL JR	.50	11	--	31	4	K10
232 HARPERS FERRY JOB CORPS	.30	12	--	4	<1	K1
233 WILLIAM JOHNSON	.20	12	--	11	<1	<1
234 ROMANO	.20	11	--	15	<1	30
235 KNODE	.20	11	--	10	8	<1
237 HENRY WILLARD JR.	.50	11	--	11	2	29
238 FRED DONLEY	.40	11	--	7	2	K1
239 HS LINK	1.1	10	--	12	<1	<1
240 PATTY JENKINS	.20	27	--	720	320	<1
241 HUGHES	.10	25	--	2000	680	<1
242 ROBERT TABB	.10	14	--	3	<1	210
243 ANIMAL WELFARE SOCIETY	.10	11	--	13	<1	<1
244 HOWARD ROPER	.20	12	<1	7	<1	110
246 DON FOWLER	.20	15	--	23	1	<1
247 GLENN JENKINS	<.10	6.5	--	9	3	<1
248 JAMES MILTON	.20	13	--	9	4	34
249 REBECCA WHIPP	.20	10	--	18	1	<1
250 STANLEY DUNN	.20	15	--	3	5	92
251 CRIM	.10	11	<1	5	<1	<1
252 HEAD SPRING	.20	10	--	3	58	K11
253 EISNER WELL	.20	11	--	4	3	<1
254 WP MILLS	.20	15	--	10	<1	<1
258 BUTLER WELL	.30	11	--	8	1	<1
259 JAMES FAUST	.20	13	--	16	10	K1
260 PARKVIEW/WOODLAND MHP	.20	12	--	<3	<1	<1
261 GREY SPRING	.20	13	--	7	<1	K2
270 LOUTHAN SPRING	.20	12	--	<3	3	51

Appendix B-2.--Ground-water chemical analyses for May 1989

Station name	Latitude	Longitude	Hydro-logic unit code	Geo-logic unit	Date	Temper-ature, water (deg C)
16 J LOUTHAN	39 11 18 N	077 54 24 W	02070007	374ELBK	05-22-89	14.0
31 V BURNS	39 13 54 N	077 53 49 W	02070004	371CCCG	05-22-89	14.5
32 A M MORGAN	39 13 28 N	077 54 31 W	02070007	371CCCG	05-22-89	13.0
34 HARRY ATHEY	39 13 47 N	077 57 20 W	02070007	367BKMN	05-22-89	12.5
43 H N RANDOLPH	39 14 18 N	077 55 41 W	02070007	371CCCG	05-23-89	13.5
58 GARY PHALEN	39 15 41 N	077 53 14 W	02070007	371CCCG	05-24-89	13.5
59 J GLENN BROWN	39 15 22 N	077 54 28 W	02070007	367BKMN	05-23-89	16.0
71B W C PERRY	39 16 16 N	077 52 12 W	02070007	374ELBK	05-23-89	13.5
88 LEO WIDMYER	39 17 24 N	077 49 04 W	02070007	374ELBK	05-23-89	13.0
91A CHARLES TOWN PS WELL PS-2	39 17 24 N	077 52 02 W	02070007	374ELBK	05-24-89	13.0
94 THOMAS MAGAHA	39 17 37 N	077 55 26 W	02070007	371CCCG	05-24-89	13.0
109 FLOWING SPRING (KANE)	39 18 40 N	077 50 40 W	02070007	371CCCG	05-23-89	13.0
109B PALMER BOYD	39 18 22 N	077 50 25 W	02070007	374ELBK	05-23-89	13.5
110A S DUNN JR	39 18 10 N	077 53 02 W	02070007	371CCCG	05-23-89	13.5
116 VICTOR BLUE	39 18 44 N	077 57 09 W	02070004	367BKMN	05-24-89	13.0
124 A N PALUMBO	39 19 27 N	077 47 50 W	02070007	377WSBR	05-24-89	13.0
139 HARPERS FERRY P S SPRING	39 20 10 N	077 45 52 W	02070007	377TMSN	05-24-89	12.0
144 FRANK W BUCKLES	39 20 37 N	077 50 56 W	02070004	371CCCG	05-24-89	13.0
146 W O LLOYD	39 20 19 N	077 52 09 W	02070007	371CCCG	05-24-89	13.5
156 WALTER WALLS	39 15 58 N	077 51 17 W	02070007	377WSBR	05-23-89	13.5
177 MILTON SKINNER	39 22 24 N	077 54 41 W	02070004	367BKMN	05-24-89	14.0
180 R W SEIDERS	39 23 52 N	077 44 33 W	02070004	377TMSN	05-25-89	13.0
206 WILLIAM H NEEDY	39 25 32 N	077 51 59 W	02070004	367BKMN	05-25-89	14.5
237 HENRY WILLARD JR.	39 24 33 N	077 45 12 W	02070004	374ELBK	05-25-89	14.0
**290 EVITTS RUN @ LIBERTY ST BRDG @ CHARLES TOWN,WV	39 17 17 N	077 51 56 W	02070007	371CCCG	05-24-89	17.5

** Site 290 is a surface water quality sampling site.

Appendix B-1.--Ground-water chemical analyses for July 1988--Continued

Station name	Strep-tococci, fecal, KF agar (Cols. per 100 mL)	Solids, residue at 180 deg. C dis-solved (mg/L)	Solids, sum of consti-tuents, dis-solved (mg/L)	Nitro-gen, ammonia, dis-solved (mg/L as NH_4)	Nitro-gen, nitrate, dis-solved (mg/L as NO_3)	Depth of well, total (feet)	Radon 222, total (pCi/L)
209 MILLARD MILLS	K13	391	328	0.03	22	26	--
213 J C DAY	K2	514	486	.03	53	270	--
230 RESEARCH INSTITUTE SPRING	K11	468	274	.01	28	--	--
231 FRANK HILL JR	40	687	624	.03	1.9	330	--
232 HARPERS FERRY JOB CORPS	K4	429	361	.05	15	325	--
233 WILLIAM JOHNSON	27	260	256	--	8.4	325	--
234 ROMANO	40	334	313	--	9.7	185	--
235 KNODE	<1	321	302	.05	12	--	--
237 HENRY WILLARD JR.	K140	487	469	.01	27	--	--
238 FRED DONLEY	K6	426	435	.06	44	250	--
239 HS LINK	<1	397	387	--	2.1	340	--
240 PATTY JENKINS	<1	191	194	.04	2.1	171	--
241 HUGHES	<1	929	951	.19	--	61	--
242 ROBERT TABB	<1	517	459	.04	25	400	--
243 ANIMAL WELFARE SOCIETY	<1	369	196	.01	36	--	--
244 HOWARD ROPER	K3	301	341	.03	23	125	--
246 DON FOWLER	<1	241	235	--	12	--	--
247 GLENN JENKINS	<1	357	293	.03	4.3	--	--
248 JAMES MILTON	K610	411	430	--	89	90	--
249 REBECCA WHIPP	K12	443	437	.03	9.7	125	--
250 STANLEY DUNN	52	626	605	.64	100	300	--
251 CRIM	<1	334	350	.01	27	180	--
252 HEAD SPRING	46	286	280	--	20	--	--
253 EISNER WELL	<1	292	285	--	19	72	--
254 WP MILLS	K1	473	453	.04	31	250	--
258 BUTLER WELL	<1	322	318	--	29	--	--
259 JAMES FAUST	<1	171	162	.01	1.9	170	850
260 PARKVIEW/WOODLAND MHP	<1	392	361	.06	24	500	--
261 GREY SPRING	K11	328	332	.01	25	--	--
270 LOUTHAN SPRING	81	332	327	--	32	--	--

Appendix B-2.--Ground-water chemical analyses for May 1989--Continued

Station name	Barometric pressure (mm of Hg)	Specific conductance (uS/cm)	Oxygen, dissolved (mg/L)	pH (standard units)	Alkalinity, wat wh tot it field (mg/L as $CaCO_3$)	Carbonate, water wh it field (mg/L as CO_3)
16 J LOUTHAN	750	1400	3.4	6.8	420	0
31 V BURNS	748	1170	3.2	7.0	385	0
32 A M MORGAN	748	870	7.2	7.0	331	0
34 HARRY ATHEY	745	920	8.1	7.0	301	0
43 H N RANDOLPH	741	1900	9.1	7.0	293	0
58 GARY PHALEN	742	735	9.0	7.0	292	0
59 J GLENN BROWN	741	700	10.0	7.3	241	0
71B W C PERRY	744	725	8.1	7.3	220	0
88 LEO WIDMYER	742	803	8.8	6.8	241	0
91A CHARLES TOWN PS WELL PS-2	745	695	6.8	7.2	261	0
94 THOMAS MAGAHA	741	790	6.5	7.2	288	0
109 FLOWING SPRING (KANE)	746	775	6.6	7.0	272	0
109B PALMER BOYD	744	715	2.0	7.5	309	0
110A S DUNN JR	742	775	2.7	6.9	357	0
116 VICTOR BLUE	744	955	6.9	7.1	304	0
124 A N PALUMBO	745	960	4.7	6.7	393	0
139 HARPERS FERRY P S SPRING	750	560	8.7	6.8	245	0
144 FRANK W BUCKLES	743	790	8.4	7.2	286	0
146 W O LLOYD	742	422	7.4	7.1	158	0
156 WALTER WALLS	742	535	9.0	7.2	200	0
177 MILTON SKINNER	743	955	6.4	6.8	361	0
180 R W SEIDERS	750	855	7.8	7.0	425	0
206 WILLIAM H NEEDY	748	1300	3.1	6.9	367	0
237 HENRY WILLARD JR.	748	1010	7.6	7.4	335	0
**290 EVITTS RUN @ LIBERTY ST BRDG @ CHARLES TOWN,WV	745	545	7.2	7.9	237	0

** Site 290 is a surface water quality sampling site.

Appendix B-2.--Ground-water chemical analyses for May 1989--Continued

Station name	Bicarbonate, water WH IT field (mg/L as HCO_3)	Nitrogen, ammonia dissolved (mg/L as NH_4)	Nitrogen, ammonia dissolved (mg/L as N)	Nitrogen, nitrite dissolved (mg/L as N)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorous ortho, dissolved (mg/L as P)	Depth of well, total (feet)
16 J LOUTHAN	512	0.12	0.090	0.07	39	<0.01	70
31 V BURNS	469	.05	.040	.03	29	<.01	160
32 A M MORGAN	404	.05	.040	<.01	18	<.01	158
34 HARRY ATHEY	367	.06	.050	<.01	20	<.01	85
43 H N RANDOLPH	357	.08	.060	<.01	13	<.01	65
58 GARY PHALEN	356	.03	.020	.02	10	.03	178
59 J GLENN BROWN	294	.05	.040	<.01	14	<.01	305
71B W C PERRY	268	.04	.030	<.01	15	<.01	200
88 LEO WIDMYER	294	.04	.030	.01	21	<.01	--
91A CHARLES TOWN PS WELL PS-2	318	.04	.030	<.01	7.7	<.01	--
94 THOMAS MAGAHA	351	.04	.030	<.01	13	<.01	146
109 FLOWING SPRING (KANE)	332	.05	.040	.02	6.2	.01	--
109B PALMER BOYD	377	.04	.030	.02	0.58	<.01	570
110A S DUNN JR	435	.06	.050	.02	22	<.01	--
116 VICTOR BLUE	371	.06	.050	<.01	14	.04	170
124 A N PALUMBO	479	.04	.030	<.01	4.7	<.01	95
139 HARPERS FERRY P S SPRING	299	.05	.040	<.01	4.2	.01	--
144 FRANK W BUCKLES	349	.04	.030	<.01	14	.02	83
146 W O LLOYD	193	.06	.050	.03	4.6	.38	--
156 WALTER WALLS	244	.04	.030	.03	10	<.01	210
177 MILTON SKINNER	440	.05	.040	<.01	9.5	<.01	98
180 R W SEIDERS	518	.05	.040	<.01	22	.02	285
206 WILLIAM H NEEDY	447	.06	.050	.01	19	<.01	95
237 HENRY WILLARD JR.	408	.04	.030	<.01	9.1	<.01	--
**290 EVITTS RUN @ LIBERTY ST BRDG @ CHARLES TOWN,WV	289	.13	.100	.04	4.7	.02	--

**Site 290 is a surface water quality sampling site.

Appendix B-3.--Quarterly chemical analyses--Continued

Station name	Barometric pressure (Mm of Hg)	Discharge, inst. cubic feet per second	Specific conductance (uS/cm)	Oxygen, dissolved (mg/L)	pH (standard units)	Alkalinity, wat wh tot it field (mg/L as $CaCO_3$)	Carbonate, water wh it field (mg/L as CO_3)
166 LEETOWN OBS WELL	753	--	596	2.0	7.5	250	0
166 LEETOWN OBS WELL	754	--	570	3.0	7.2	254	0
166 LEETOWN OBS WELL	752	--	645	3.3	6.7	298	0
166 LEETOWN OBS WELL	752	--	660	3.3	7.1	288	0
236 SHEPHERDSTOWN OBS WELL	751	--	670	3.5	7.0	254	0
236 SHEPHERDSTOWN OBS WELL	750	--	905	3.5	7.2	339	0
236 SHEPHERDSTOWN OBS WELL	751	--	740	5.3	7.1	311	0
236 SHEPHERDSTOWN OBS WELL	751	--	910	2.2	7.2	295	0
245 ALDRIDGE SPRING	750	0.72	400	9.5	7.7	165	0
245 ALDRIDGE SPRING	749	.33	540	11.2	7.4	242	0
245 ALDRIDGE SPRING	750	1.6	575	8.8	6.9	255	0
245 ALDRIDGE SPRING	746	1.8	505	10.4	7.3	**230	**0
252 HEAD SPRING	754	.47	496	9.0	7.6	224	0
252 HEAD SPRING	751	.20	480	9.0	8.1	222	0
252 HEAD SPRING	745	.70	505	7.9	7.1	230	0
252 HEAD SPRING	744	.89	438	9.0	7.3	204	0
255 RIPPON OBS WELL	750	--	900	0.8	7.5	380	0
255 RIPPON OBS WELL	751	--	875	6.5	>7.2	341	0
255 RIPPON OBS WELL	751	--	950	3.5	7.0	390	0
255 RIPPON OBS WELL	748	--	795	1.3	7.0	355	0
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	761	2.3	565	9.2	8.2	280	0
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	756	1.7	559	12.6	7.4	255	0
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	751	3.7	590	8.1	7.6	259	0
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	749	4.0	670	8.0	7.8	247	0
257 BULLSKIN RUN AT KABLETOWN,WV	761	9.5	560	8.5	7.8	232	0
257 BULLSKIN RUN AT KABLETOWN,WV	757	8.0	560	13.5	7.9	229	0
257 BULLSKIN RUN AT KABLETOWN,WV	752	19	555	9.0	7.8	270	0
257 BULLSKIN RUN AT KABLETOWN,WV	751	19	560	8.6	7.6	248	0

** This analysis was conducted on the dissolved constituents only.

Appendix B-3.--Quarterly chemical analyses

Station name	Latitude	Longitude	Hydro-logic unit code	Geo-logic unit	Date	Temper-ature, water (deg C)
166 LEETOWN OBS WELL	39 21 04 N	077 55 48 W	02070007	367BKMN	09-28-88	14.0
166 LEETOWN OBS WELL	39 21 04 N	077 55 48 W	02070007	367BKMN	12-20-88	13.0
166 LEETOWN OBS WELL	39 21 04 N	077 55 48 W	02070007	367BKMN	03-28-89	12.5
166 LEETOWN OBS WELL	39 21 04 N	077 55 48 W	02070007	367BKMN	06-19-89	13.0
236 SHEPHERDSTOWN OBS WELL	39 24 57 N	077 50 13 W	02070004	371CCCG	09-27-88	13.0
236 SHEPHERDSTOWN OBS WELL	39 24 57 N	077 50 13 W	02070004	371CCCG	12-19-88	12.5
236 SHEPHERDSTOWN OBS WELL	39 24 57 N	077 50 13 W	02070004	371CCCG	03-27-89	14.0
236 SHEPHERDSTOWN OBS WELL	39 24 57 N	077 50 13 W	02070004	371CCCG	06-20-89	14.0
245 ALDRIDGE SPRING	39 18 05 N	077 55 07 W	02070007	371CCCG	09-27-88	17.0
245 ALDRIDGE SPRING	39 18 05 N	077 55 07 W	02070007	371CCCG	12-20-88	6.5
245 ALDRIDGE SPRING	39 18 05 N	077 55 07 W	02070007	371CCCG	03-28-89	15.0
245 ALDRIDGE SPRING	39 18 05 N	077 55 07 W	02070007	371CCCG	06-20-89	15.5
252 HEAD SPRING	39 14 13 N	077 57 23 W	02070007	371CCCG	09-29-88	13.5
252 HEAD SPRING	39 14 13 N	077 57 23 W	02070007	371CCCG	12-21-88	8.5
252 HEAD SPRING	39 14 13 N	077 57 23 W	02070007	371CCCG	03-29-89	15.0
252 HEAD SPRING	39 14 13 N	077 57 23 W	02070007	371CCCG	06-20-89	17.0
255 RIPPON OBS WELL	39 11 42 N	077 55 17 W	02070007	371CCCG	09-28-88	12.5
255 RIPPON OBS WELL	39 11 42 N	077 55 17 W	02070007	371CCCG	12-20-88	12.5
255 RIPPON OBS WELL	39 11 42 N	077 55 17 W	02070007	371CCCG	03-27-89	13.0
255 RIPPON OBS WELL	39 11 42 N	077 55 17 W	02070007	371CCCG	06-20-89	15.0
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	39 11 09 N	077 52 47 W	02070007	374ELBK	09-29-88	13.5
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	39 11 09 N	077 52 47 W	02070007	374ELBK	12-21-88	8.5
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	39 11 09 N	077 52 47 W	02070007	374ELBK	03-28-89	22.5
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	39 11 09 N	077 52 47 W	02070007	374ELBK	06-21-89	21.5
257 BULLSKIN RUN AT KABLETOWN,WV	39 12 57 N	077 51 25 W	02070007	374ELBK	09-29-88	13.5
257 BULLSKIN RUN AT KABLETOWN,WV	39 12 57 N	077 51 25 W	02070007	374ELBK	12-21-88	9.0
257 BULLSKIN RUN AT KABLETOWN,WV	39 12 57 N	077 51 25 W	02070007	374ELBK	03-28-89	17.0
257 BULLSKIN RUN AT KABLETOWN,WV	39 12 57 N	077 51 25 W	02070007	374ELBK	06-21-89	19.5

Appendix B-3.--Quarterly chemical analyses--Continued

Station name	Bicarbonate, water wh it field (mg/L as HCO_3)	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, Nitrate, dissolved (mg/L as N)	Nitrogen, NO2+NO3 dissolved (mg/L as N)
166 LEETOWN OBS WELL	310	5.20	0.03	1.2	1.2
166 LEETOWN OBS WELL	309	0.10	.05	1.8	1.9
166 LEETOWN OBS WELL	363	.02	<.01	--	3.0
166 LEETOWN OBS WELL	351	.02	<.01	--	3.1
236 SHEPHERDSTOWN OBS WELL	310	.05	.01	1.6	1.6
236 SHEPHERDSTOWN OBS WELL	413	.10	<.01	--	0.11
236 SHEPHERDSTOWN OBS WELL	379	.03	<.01	--	.92
236 SHEPHERDSTOWN OBS WELL	360	.07	<.01	--	<.10
245 ALDRIDGE SPRING	200	.04	.04	4.1	4.1
245 ALDRIDGE SPRING	295	.55	.17	3.5	3.7
245 ALDRIDGE SPRING	311	.06	.04	4.6	4.6
245 ALDRIDGE SPRING	**280	.03	.06	4.5	4.6
252 HEAD SPRING	273	.04	.02	5.2	5.2
252 HEAD SPRING	271	.26	.06	5.0	5.1
252 HEAD SPRING	280	.08	.02	5.4	5.4
252 HEAD SPRING	249	.07	<.01	--	4.6
255 RIPPON OBS WELL	460	.17	.08	0.48	.56
255 RIPPON OBS WELL	416	.07	<.01	--	<.10
255 RIPPON OBS WELL	475	.12	<.01	--	.16
255 RIPPON OBS WELL	433	.07	<.01	--	<.10
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	340	.12	.05	6.4	6.4
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	311	.18	.04	6.5	6.5
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	316	.09	.03	5.4	5.4
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	301	.07	.04	6.8	6.8
257 BULLSKIN RUN AT KABLETOWN,WV	280	.11	.03	6.7	6.7
257 BULLSKIN RUN AT KABLETOWN,WV	280	.07	.02	6.6	6.6
257 BULLSKIN RUN AT KABLETOWN,WV	329	.04	.01	6.5	6.5
257 BULLSKIN RUN AT KABLETOWN,WV	302	.03	.03	6.8	6.8

** This analysis was conducted on the dissolved constituents only.

Station name	Phos-phorous ortho, dis-solved (mg/L as P)	Hard-ness, total (mg/L as $CaCO_3$)	Hard-ness, noncarb wh wat tot fld (mg/L as $CaCO_3$)	Calcium, dis-solved (mg/L as Ca)	Magne-sium, dis-solved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)
166 LEETOWN OBS WELL	<0.01	220	3	76	7.7	17	12
166 LEETOWN OBS WELL	<.01	280	20	100	7.4	6.6	3.1
166 LEETOWN OBS WELL	<.01	330	38	120	8.4	5.9	1.7
166 LEETOWN OBS WELL	<.01	310	59	110	8.1	5.1	1.8
236 SHEPHERDSTOWN OBS WELL	<.01	320	63	83	28	16	2.3
236 SHEPHERDSTOWN OBS WELL	<.01	400	74	90	42	27	2.6
236 SHEPHERDSTOWN OBS WELL	<.01	350	64	89	32	18	1.4
236 SHEPHERDSTOWN OBS WELL	<.01	370	180	84	39	38	2.2
245 ALDRIDGE SPRING	<.01	200	35	69	6.5	1.7	1.6
245 ALDRIDGE SPRING	<.01	260	21	93	6.8	2.4	3.0
245 ALDRIDGE SPRING	<.01	300	49	110	5.9	2.9	1.3
245 ALDRIDGE SPRING	<.01	260	28	93	6.2	2.4	1.6
252 HEAD SPRING	<.01	250	60	88	7.9	2.0	1.9
252 HEAD SPRING	<.01	250	24	86	8.0	2.3	2.8
252 HEAD SPRING	<.01	250	34	89	7.3	2.4	2.4
252 HEAD SPRING	.02	220	23	76	6.2	2.4	2.5
255 RIPPON OBS WELL	<.01	460	85	100	50	10	17
255 RIPPON OBS WELL	<.01	440	87	97	48	10	18
255 RIPPON OBS WELL	<.01	470	100	110	48	11	26
255 RIPPON OBS WELL	<.01	400	58	91	43	6.6	13
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	.03	290	47	93	14	3.7	2.5
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	.01	270	39	87	13	3.8	3.0
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	.01	300	63	92	18	4.7	3.4
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	.01	290	47	89	16	4.3	3.5
257 BULLSKIN RUN AT KABLETOWN,WV	.01	290	92	90	15	3.7	2.8
257 BULLSKIN RUN AT KABLETOWN,WV	<.01	280	42	86	15	4.5	2.8
257 BULLSKIN RUN AT KABLETOWN,WV	<.01	290	53	95	14	5.9	2.0
257 BULLSKIN RUN AT KABLETOWN,WV	.01	270	39	87	14	4.1	2.9

Appendix B-3.--Quarterly chemical analyses--Continued

Station name	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Iron, dissolved (ug/L as Fe)	Manganese, dissolved (ug/L as Mn)	Coliform, fecal, 0.7 UM-MF (Cols./100 mL)
166 LEETOWN OBS WELL	19	10	0.10	6.0	9	330	K160
166 LEETOWN OBS WELL	12	26	.10	7.7	420	200	<1
166 LEETOWN OBS WELL	13	25	.10	9.4	47	12	<1
166 LEETOWN OBS WELL	11	24	.10	9.3	78	61	--
236 SHEPHERDSTOWN OBS WELL	32	39	.30	12	5	11	K22
236 SHEPHERDSTOWN OBS WELL	63	51	.60	12	1300	78	<1
236 SHEPHERDSTOWN OBS WELL	32	38	.40	13	29	10	<1
236 SHEPHERDSTOWN OBS WELL	81	47	.90	11	1600	55	K4
245 ALDRIDGE SPRING	4.2	16	.10	7.6	9	3	K13
245 ALDRIDGE SPRING	5.8	15	.10	11	17	39	25
245 ALDRIDGE SPRING	7.1	15	.10	8.8	7	13	300
245 ALDRIDGE SPRING	5.9	14	.20	9.7	29	2	K200
252 HEAD SPRING	5.6	11	.10	11	10	6	K710
252 HEAD SPRING	5.6	12	.10	11	18	12	K280
252 HEAD SPRING	5.9	13	.10	11	16	16	K1800
252 HEAD SPRING	6.1	11	.10	9.2	8	1	K2300
255 RIPPON OBS WELL	16	98	.60	11	340	65	33
255 RIPPON OBS WELL	15	110	.50	10	340	55	<1
255 RIPPON OBS WELL	16	120	.60	10	1100	48	<1
255 RIPPON OBS WELL	11	68	.80	11	800	37	<1
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	10	18	.20	12	16	38	K1400
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	9.5	19	.20	11	22	13	K11000
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	12	25	.30	10	21	33	K1100
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	11	20	.40	11	17	7	K7
257 BULLSKIN RUN AT KABLETOWN,WV	11	17	.20	11	16	8	K2000
257 BULLSKIN RUN AT KABLETOWN,WV	11	19	.20	8.6	7	7	K280
257 BULLSKIN RUN AT KABLETOWN,WV	13	21	.20	9.5	16	18	190
257 BULLSKIN RUN AT KABLETOWN,WV	11	16	.30	11	13	4	K7200

Appendix B-3.--Quarterly chemical analyses--Continued

Station name	Streptococci, fecal, KF agar (Cols. per 100 mL)	Solids, residue at 180 Deg. C dissolved (mg/L)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, ammonia, dissolved (mg/L as NH_4)	Depth of well, total (feet)
166 LEETOWN OBS WELL	K140	294	291	6.7	160
166 LEETOWN OBS WELL	28	332	329	0.13	160
166 LEETOWN OBS WELL	<1	375	375	.03	160
166 LEETOWN OBS WELL	54	354	333	.03	160
236 SHEPHERDSTOWN OBS WELL	K200	377	376	.06	180
236 SHEPHERDSTOWN OBS WELL	K3	486	484	.13	180
236 SHEPHERDSTOWN OBS WELL	K2	397	402	.04	180
236 SHEPHERDSTOWN OBS WELL	59	497	422	.09	180
245 ALDRIDGE SPRING	28	223	223	.05	--
245 ALDRIDGE SPRING	200	306	298	.71	--
245 ALDRIDGE SPRING	82	299	322	.08	--
245 ALDRIDGE SPRING	96	282	291	.04	--
252 HEAD SPRING	56	279	266	.05	--
252 HEAD SPRING	K1700	279	285	.33	--
252 HEAD SPRING	170	280	286	.10	--
252 HEAD SPRING	K3200	231	250	.09	--
255 RIPPON OBS WELL	63	515	528	.22	153
255 RIPPON OBS WELL	<1	540	521	.09	153
255 RIPPON OBS WELL	<1	545	565	.15	153
255 RIPPON OBS WELL	K15	452	453	.09	153
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	K600	317	328	.15	--
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	K620	312	315	.23	--
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	180	337	334	.12	--
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	1300	324	330	.09	--
257 BULLSKIN RUN AT KABLETOWN,WV	K1000	317	297	.14	--
257 BULLSKIN RUN AT KABLETOWN,WV	K1000	314	317	.09	--
257 BULLSKIN RUN AT KABLETOWN,WV	82	308	334	.05	--
257 BULLSKIN RUN AT KABLETOWN,WV	K2000	243	318	.04	--

Appendix B-4.--Surface-water chemical analyses

Station name	Latitude	Longitude	Hydro-logic unit code	Geo-logic unit	Date
138 BULLSKIN RUN NR WHEAT LAND	39 14 16 N	077 54 15 W	02070007	371CCCG	08-03-88
140 EVITTS RUN NR CHARLES TOWN	39 17 47 N	077 53 59 W	02070007	371CCCG	08-04-88
145 ROCKYMARSH RUN TRIB NR SHEPARDSTOWN	39 26 09 N	077 51 35 W	02070004	367BKMN	08-02-88
148 ROCKYMARSH RUN TRIB NR SCRABBLE	39 28 04 N	077 50 12 W	02070004	371CCCG	08-02-88
151 RATTLESNAKE RUN NR SHEPARDSTOWN	39 23 35 N	077 48 31 W	02070004	371CCCG	08-02-88
153 LONG MARSH RUN TRIB NR FRANKLINTOWN	39 11 48 N	077 53 50 W	02070007	374ELBK	08-03-88
156 ELKS RUN TRIB NR HARPERS FERRY	39 20 04 N	077 45 42 W	02070004	377TMSN	08-03-88
157 ROCKY BRANCH NR. MYERSTOWN	39 09 35 N	077 50 43 W	02070007	377ANTM	08-03-88
159 FURNACE RUN NR MOUNTAIN MISSION	39 13 10 N	077 48 58 W	02070007	377ANTM	08-03-88
160 FORGE RUN NR MOUNTAIN MISSION	39 14 45 N	077 47 37 W	02070007	377CHLH	08-03-88
161 SHENANDOAH R TRIB NR SILVER GROVE	39 16 33 N	077 46 07 W	02070004	377CHLH	08-03-88
225 SHENANDOAH RIVER AT MILLVILLE, WV	39 16 55 N	077 47 22 W	02070007	-------	08-03-88

Station name	Temper-ature, water (deg C)	Baro-metric pres-sure (Mm of Hg)	Dis-charge, inst. cubic feet per second	Spe-cific con-duct-ance (uS/cm)	Oxygen, dis-solved (mg/L)	pH (stand-ard units)
138 BULLSKIN RUN NR WHEAT LAND	20.0	754	4.0	510	7.8	7.6
140 EVITTS RUN NR CHARLES TOWN	20.5	753	2.2	495	6.1	7.6
145 ROCKYMARSH RUN TRIB NR SHEPARDSTOWN	26.0	752	1.4	595	5.8	8.1
148 ROCKYMARSH RUN TRIB NR SCRABBLE	14.0	753	2.2	555	6.0	7.1
151 RATTLESNAKE RUN NR SHEPARDSTOWN	24.0	752	0.48	260	>10.0	7.6
153 LONG MARSH RUN TRIB NR FRANKLINTOWN	22.0	755	2.3	540	7.3	7.8
156 ELKS RUN TRIB NR HARPERS FERRY	21.0	759	.10	625	7.1	8.1
157 ROCKY BRANCH NR. MYERSTOWN	24.0	752	.10	37	6.0	6.8
159 FURNACE RUN NR MOUNTAIN MISSION	26.5	758	1.3	52	6.4	7.7
160 FORGE RUN NR MOUNTAIN MISSION	24.5	756	.14	132	6.8	7.8
161 SHENANDOAH R TRIB NR SILVER GROVE	23.5	756	.03	235	5.8	7.9
225 SHENANDOAH RIVER AT MILLVILLE, WV	29.5	759	624	485	5.8	8.4

Appendix B-4.--Surface-water chemical analyses--Continued

Station name	Nitrogen, ammonia, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO2+NO3 dissolved (mg/L as N)	Phosphorous ortho, dissolved (mg/L as P)	Hardness, total (mg/L as $CaCO_3$)
138 BULLSKIN RUN NR WHEAT LAND	0.10	0.03	4.2	0.03	270
140 EVITTS RUN NR CHARLES TOWN	*.02	*.03	*3.3	*<.01	270
145 ROCKYMARSH RUN TRIB NR SHEPARDSTOWN	*.03	*.03	*3.4	*<.01	310
148 ROCKYMARSH RUN TRIB NR SCRABBLE	.02	<.01	3.2	.02	300
151 RATTLESNAKE RUN NR SHEPARDSTOWN	.83	.13	4.1	.02	310
153 LONG MARSH RUN TRIB NR FRANKLINTOWN	*.06	*.04	*6.1	*<.01	290
156 ELKS RUN TRIB NR HARPERS FERRY	.02	<.01	0.99	.01	340
157 ROCKY BRANCH NR. MYERSTOWN	.02	<.01	.17	<.01	14
159 FURNACE RUN NR MOUNTAIN MISSION	.02	<.01	<.10	.01	20
160 FORGE RUN NR MOUNTAIN MISSION	*.03	*<.01	*.35	*.02	61
161 SHENANDOAH R TRIB NR SILVER GROVE	.02	<.01	.27	<.01	110
225 SHENANDOAH RIVER AT MILLVILLE, WV	.04	.02	.58	.03	170

* Sample damaged during shipment to laboratory, resampled on August 25, 1988.

Station name	Hardness, noncarb wh wat tot fld (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Chloride, dissolved (mg/L as Cl)	Nitrogen, ammonia, dissolved (mg/L as NH_4)
138 BULLSKIN RUN NR WHEAT LAND	41	95	8.1	7.7	0.13
140 EVITTS RUN NR CHARLES TOWN	28	95	7.3	12	*.03
145 ROCKYMARSH RUN TRIB NR SHEPARDSTOWN	41	110	9.7	5.6	*.04
148 ROCKYMARSH RUN TRIB NR SCRABBLE	38	100	12	9.0	.03
151 RATTLESNAKE RUN NR SHEPARDSTOWN	43	98	15	11	1.1
153 LONG MARSH RUN TRIB NR FRANKLINTOWN	60	96	12	10	*.08
156 ELKS RUN TRIB NR HARPERS FERRY	28	74	37	16	.03
157 ROCKY BRANCH NR. MYERSTOWN	3	2.7	1.7	1.6	.03
159 FURNACE RUN NR MOUNTAIN MISSION	2	4.6	2.1	2.4	.03
160 FORGE RUN NR MOUNTAIN MISSION	1	15	5.6	3.5	*.04
161 SHENANDOAH R TRIB NR SILVER GROVE	11	29	9.7	6.2	.03
225 SHENANDOAH RIVER AT MILLVILLE, WV	43	45	15	17	.05

* Sample damaged during shipment to laboratory, resampled on August 25, 1988.

Appendix B-5.--Surface- and ground-water organochlorine and organophosphate chemical analyses (includes PCB's and PCN's)

Station name	Latitude	Longitude	Date	Aldrin, total (ug/L)	Chlordane, total (ug/L)	DDD, total (ug/L)
16 J LOUTHAN	39 11 18 N	077 54 24 W	07-25-88	<0.001	<0.1	<0.001
22 D N HOOVER	39 12 00 N	077 52 03 W	07-26-88	<.001	<.1	<.001
28 P B ROGERS	39 13 37 N	077 50 44 W	07-25-88	<.001	<.1	<.001
31 V BURNS	39 13 54 N	077 53 49 W	07-26-88	<.001	<.1	<.001
42 W MICKEY	39 14 49 N	077 53 14 W	07-26-88	<.001	<.1	<.001
63 RANDOLPH BURCH	39 15 20 N	078 00 08 W	07-29-88	<.001	<.1	<.001
71B W C PERRY	39 16 16 N	077 52 12 W	07-28-88	<.001	<.1	<.001
73 FRANK PAPIANO	39 16 57 N	077 53 48 W	07-27-88	<.001	<.1	<.001
88A CATTAIL SPRING	39 16 55 N	077 49 38 W	07-27-88	<.001	<.1	<.001
106 C L ROBINSON	39 18 54 N	077 48 46 W	07-27-88	<.001	<.1	<.001
109 FLOWING SPRING (KANE)	39 18 40 N	077 50 40 W	07-25-88	<.001	<.1	<.001
126 RODERICK BROS	39 19 52 N	077 49 56 W	07-26-88	<.001	<.1	<.001
139 HARPERS FERRY P S SPRING	39 20 10 N	077 45 52 W	07-26-88	<.001	<.1	<.001
156 KENNETH WILT	39 21 28 N	077 46 29 W	07-26-88	<.001	<.1	<.001
160 PAUL CHAPMAN	39 21 17 N	077 50 29 W	07-28-88	<.001	<.1	<.001
176 HOLLIS-LOWMAN	39 22 43 N	077 53 35 W	07-28-88	<.001	<.1	<.001
198 FORREST HAMMOND	39 24 48 N	077 52 41 W	07-28-88	<.001	<.1	<.001
232 HARPERS FERRY JOB CORPS	39 20 45 N	077 48 44 W	07-26-88	<.001	<.1	<.001
233 WILLIAM JOHNSON	39 27 43 N	077 48 10 W	07-27-88	<.001	<.1	<.001
238 FRED DONLEY	39 23 44 N	077 45 53 W	07-27-88	<.001	<.1	<.001
239 HS LINK	39 23 27 N	077 50 42 W	07-28-88	<.001	<.1	<.001
242 ROBERT TABB	39 19 47 N	077 55 08 W	07-27-88	<.001	<.1	<.001
243 ANIMAL WELFARE SOCIETY	39 20 02 N	077 54 37 W	07-28-88	<.001	<.1	<.001
244 HOWARD ROPER	39 20 32 N	077 53 04 W	07-28-88	<.001	<.1	<.001
245 ALDRIDGE SPRING	39 18 05 N	077 55 07 W	09-27-88	<.001	<.1	<.001
245 ALDRIDGE SPRING	39 18 05 N	077 55 07 W	12-20-88	<.001	<.1	<.001
245 ALDRIDGE SPRING	39 18 05 N	077 55 07 W	03-28-89	<.001	<.1	<.001
245 ALDRIDGE SPRING	39 18 05 N	077 55 07 W	06-20-89	<.001	<.1	<.001
247 GLENN JENKINS	39 17 54 N	077 57 09 W	07-27-88	<.001	<.1	<.001
249 REBECCA WHIPP	39 17 27 N	077 47 18 W	07-26-88	<.001	<.1	<.001
250 STANLEY DUNN	39 18 15 N	077 52 59 W	07-28-88	<.001	<.1	<.001
251 CRIM	39 15 32 N	077 56 27 W	07-28-88	<.001	<.1	<.001
252 HEAD SPRING	39 14 13 N	077 57 23 W	09-29-88	<.001	<.1	<.001
252 HEAD SPRING	39 14 13 N	077 57 23 W	12-21-88	<.001	<.1	<.001
252 HEAD SPRING	39 14 13 N	077 57 23 W	03-29-89	<.001	<.1	<.001
252 HEAD SPRING	39 14 13 N	077 57 23 W	06-20-89	<.001	<.1	<.001
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	39 11 09 N	077 52 47 W	09-29-88	<.001	<.1	.001
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	39 11 09 N	077 52 47 W	12-21-88	<.001	<.1	<.001
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	39 11 09 N	077 52 47 W	03-28-89	<.001	<.1	.002
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	39 11 09 N	077 52 47 W	06-21-89	<.001	<.1	<.001
257 BULLSKIN RUN AT KABLETOWN,WV	39 12 57 N	077 51 25 W	09-29-88	<.001	<.1	<.001
257 BULLSKIN RUN AT KABLETOWN,WV	39 12 57 N	077 51 25 W	12-21-88	<.001	<.1	<.001
257 BULLSKIN RUN AT KABLETOWN,WV	39 12 57 N	077 51 25 W	03-28-89	<.001	<.1	<.001
257 BULLSKIN RUN AT KABLETOWN,WV	39 12 57 N	077 51 25 W	06-21-89	<.001	<.1	<.001
258 BUTLER WELL	39 13 32 N	077 48 47 W	07-27-88	<.001	<.1	<.001
270 LOUTHAN SPRING	39 11 53 N	077 54 50 W	07-29-88	<.001	<.1	<.001

Appendix B-5.--Surface- and ground-water organochlorine and organophosphate chemical analyses--Continued

Station name	DDE, total (ug/L)	DDT, total (ug/L)	Di-azinon, total (ug/L)	Di-eldrin, total (ug/L)	Endo-sulfan, total (UG/L)	Endrin, total (ug/L)	Ethion, total (ug/L)
16 J LOUTHAN	<0.001	<0.001	<0.01	<0.001	<0.001	<0.001	<0.01
22 D N HOOVER	<.001	<.001	<.01	<.001	<.001	<.001	<.01
28 P B ROGERS	<.001	<.001	<.01	<.001	<.001	<.001	<.01
31 V BURNS	<.001	<.001	<.01	<.001	<.001	<.001	<.01
42 W MICKEY	<.001	<.001	<.01	<.001	<.001	.150	<.01
63 RANDOLPH BURCH	<.001	<.001	<.01	<.001	<.001	<.001	<.01
71B W C PERRY	<.001	<.001	<.01	<.001	<.001	<.001	<.01
73 FRANK PAPIANO	<.001	<.001	<.01	<.001	<.001	<.001	<.01
88A CATTAIL SPRING	<.001	<.001	<.01	<.001	<.001	.018	<.01
106 C L ROBINSON	<.001	<.001	<.01	.002	<.001	.015	<.01
109 FLOWING SPRING (KANE)	<.001	<.001	<.01	.002	<.001	<.001	<.01
126 RODERICK BROS	<.001	<.001	<.01	<.001	<.001	<.001	<.01
139 HARPERS FERRY P S SPRING	<.001	<.001	<.01	<.001	<.001	<.001	<.01
156 KENNETH WILT	<.001	<.001	<.01	<.001	<.001	<.001	<.01
160 PAUL CHAPMAN	<.001	<.001	<.01	<.001	<.001	<.001	<.01
176 HOLLIS-LOWMAN	<.001	<.001	<.01	<.001	<.001	.006	<.01
198 FORREST HAMMOND	<.001	<.001	<.01	<.001	<.001	<.001	<.01
232 HARPERS FERRY JOB CORPS	<.001	<.001	<.01	<.001	<.001	<.001	<.01
233 WILLIAM JOHNSON	<.001	<.001	<.01	<.001	<.001	<.001	<.01
238 FRED DONLEY	<.001	<.001	<.01	<.001	<.001	<.001	<.01
239 HS LINK	<.001	<.001	<.01	<.001	<.001	.007	<.01
242 ROBERT TABB	<.001	<.001	<.01	<.001	<.001	<.001	<.01
243 ANIMAL WELFARE SOCIETY	<.001	<.001	<.01	<.001	<.001	<.001	<.01
244 HOWARD ROPER	<.001	<.001	<.01	<.001	<.001	<.001	<.01
245 ALDRIDGE SPRING	<.001	<.001	<.01	<.001	<.001	<.001	<.01
245 ALDRIDGE SPRING	<.001	<.001	<.01	<.001	<.001	<.001	<.01
245 ALDRIDGE SPRING	<.001	<.001	<.01	<.001	<.001	<.001	<.01
245 ALDRIDGE SPRING	<.001	<.001	<.01	<.001	<.001	<.001	<.01
247 GLENN JENKINS	<.001	<.001	<.01	<.001	<.001	<.001	<.01
249 REBECCA WHIPP	<.001	<.001	<.01	<.001	<.001	<.001	<.01
250 STANLEY DUNN	<.001	<.001	<.01	<.001	<.001	<.001	<.01
251 CRIM	<.001	<.001	<.01	<.001	<.001	<.001	<.01
252 HEAD SPRING	<.001	<.001	<.01	<.001	<.001	<.001	<.01
252 HEAD SPRING	<.001	<.001	<.01	<.001	<.001	<.001	<.01
252 HEAD SPRING	.001	<.001	<.01	<.001	<.001	<.001	<.01
252 HEAD SPRING	<.001	<.001	<.01	<.001	<.001	<.001	<.01
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	.005	.005	<.01	<.001	<.001	<.001	<.01
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	.002	<.001	<.01	<.001	<.001	<.001	<.01
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	.006	.003	<.01	<.001	<.001	<.001	<.01
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	.001	<.001	<.01	<.001	<.001	<.001	<.01
257 BULLSKIN RUN AT KABLETOWN,WV	.003	.001	<.01	<.001	<.001	<.001	<.01
257 BULLSKIN RUN AT KABLETOWN,WV	<.001	<.001	<.01	<.001	<.001	.005	<.01
257 BULLSKIN RUN AT KABLETOWN,WV	<.001	.005	<.01	<.001	<.001	<.001	<.01
257 BULLSKIN RUN AT KABLETOWN,WV	<.001	<.001	<.01	<.001	<.001	<.001	<.01
258 BUTLER WELL	.002	<.001	<.01	.003	<.001	.031	<.01
270 LOUTHAN SPRING	<.001	<.001	<.01	.001	<.001	<.001	<.01

Appendix B-5.--Surface- and ground-water organochlorine and organophosphate chemical analyses--Continued

Station name	Biphenyls, polychlorinated, total (ug/L)	Naphthalenes, polychlor, total (ug/L)	Heptachlor, total (ug/L)	Heptachlor epoxide, total (ug/L)	Lindane, total (ug/L)	Malathion, total (ug/L)	Methoxychlor, total (ug/L)
16 J LOUTHAN	<0.1	<0.10	<0.001	<0.001	<0.001	<0.01	<0.01
22 D N HOOVER	<.1	<.10	<.001	<.001	<.001	<.01	<.01
28 P B ROGERS	<.1	<.10	<.001	<.001	<.001	<.01	<.01
31 V BURNS	<.1	<.10	<.001	<.001	<.001	<.01	<.01
42 W MICKEY	<.1	<.10	<.001	<.001	<.001	<.01	<.01
63 RANDOLPH BURCH	<.1	<.10	<.001	<.001	<.001	<.01	<.01
71B W C PERRY	<.1	<.10	<.001	<.001	<.001	<.01	<.01
73 FRANK PAPIANO	<.1	<.10	<.001	<.001	<.001	<.01	<.01
88A CATTAIL SPRING	<.1	<.10	<.001	<.001	<.001	<.01	<.01
106 C L ROBINSON	<.1	<.10	<.001	<.001	<.001	<.01	<.01
109 FLOWING SPRING (KANE)	<.1	<.10	<.001	<.001	<.001	<.01	<.01
126 RODERICK BROS	<.1	<.10	<.001	<.001	<.001	<.01	<.01
139 HARPERS FERRY P S SPRING	<.1	<.10	<.001	<.001	<.001	<.01	<.01
156 KENNETH WILT	<.1	<.10	<.001	<.001	<.001	<.01	<.01
160 PAUL CHAPMAN	<.1	<.10	<.001	<.001	<.001	<.01	<.01
176 HOLLIS-LOWMAN	<.1	<.10	<.001	<.001	<.001	<.01	<.01
198 FORREST HAMMOND	<.1	<.10	<.001	<.001	<.001	<.01	<.01
232 HARPERS FERRY JOB CORPS	<.1	<.10	<.001	<.001	<.001	<.01	<.01
233 WILLIAM JOHNSON	<.1	<.10	<.001	<.001	<.001	<.01	<.01
238 FRED DONLEY	<.1	<.10	.002	<.001	<.001	<.01	<.01
239 HS LINK	<.1	<.10	<.001	<.001	<.001	<.01	<.01
242 ROBERT TABB	<.1	<.10	<.001	<.001	<.001	<.01	<.01
243 ANIMAL WELFARE SOCIETY	<.1	<.10	<.001	<.001	<.001	<.01	<.01
244 HOWARD ROPER	<.1	<.10	<.001	<.001	<.001	<.01	<.01
245 ALDRIDGE SPRING	<.1	<.10	<.001	<.001	<.001	<.01	<.01
245 ALDRIDGE SPRING	<.1	<.10	<.001	<.001	<.001	<.01	<.01
245 ALDRIDGE SPRING	<.1	<.10	<.001	<.001	<.001	<.01	<.01
245 ALDRIDGE SPRING	<.1	<.10	<.001	<.001	<.001	<.01	<.01
247 GLENN JENKINS	<.1	<.10	<.001	<.001	<.001	<.01	<.01
249 REBECCA WHIPP	<.1	<.10	<.001	<.001	<.001	<.01	<.01
250 STANLEY DUNN	<.1	<.10	<.001	<.001	<.001	<.01	<.01
251 CRIM	<.1	<.10	<.001	<.001	<.001	<.01	<.01
252 HEAD SPRING	<.1	<.10	<.001	<.001	<.001	<.01	<.01
252 HEAD SPRING	<.1	<.10	<.001	<.001	<.001	<.01	<.01
252 HEAD SPRING	<.1	<.10	<.001	<.001	<.001	<.01	<.01
252 HEAD SPRING	<.1	<.10	<.001	<.001	<.001	<.01	<.01
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	<.1	<.10	<.001	<.001	<.001	<.01	<.01
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	<.1	<.10	<.001	<.001	<.001	<.01	<.01
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	<.1	<.10	<.001	<.001	<.001	<.01	<.01
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	<.1	<.10	<.001	<.001	<.001	<.01	<.01
257 BULLSKIN RUN AT KABLETOWN,WV	<.1	<.10	<.001	<.001	<.001	<.01	<.01
257 BULLSKIN RUN AT KABLETOWN,WV	<.1	<.10	<.001	<.001	<.001	<.01	<.01
257 BULLSKIN RUN AT KABLETOWN,WV	<.1	<.10	<.001	<.001	<.001	<.01	<.01
257 BULLSKIN RUN AT KABLETOWN,WV	<.1	<.10	<.001	<.001	<.001	<.01	<.01
258 BUTLER WELL	<.1	<.10	<.001	<.001	<.001	<.01	<.01
270 LOUTHAN SPRING	<.1	<.10	<.001	<.001	<.001	<.01	<.01

Appendix B-5.--Surface- and ground-water organochlorine and organophosphate chemical analyses--Continued

Station name	Methyl para-thion, total (ug/L)	Methyl tri-thion, total (ug/L)	Mirex, total (ug/L)	Para-thion, total (ug/L)	Per-thane, total (ug/L)	Tox-aphene, total (ug/L)	Tri-thion, total (ug/L)
16 J LOUTHAN	<0.01	<0.01	<0.01	<0.01	<0.1	<1	<0.01
22 D N HOOVER	<.01	<.01	<.01	<.01	<.1	<1	<.01
28 P B ROGERS	<.01	<.01	<.01	<.01	<.1	<1	<.01
31 V BURNS	<.01	<.01	<.01	<.01	<.1	<1	<.01
42 W MICKEY	<.01	<.01	<.01	<.01	<.1	<1	<.01
63 RANDOLPH BURCH	<.01	<.01	<.01	<.01	<.1	<1	<.01
71B W C PERRY	<.01	<.01	<.01	<.01	<.1	<1	<.01
73 FRANK PAPIANO	<.01	<.01	<.01	<.01	<.1	<1	<.01
88A CATTAIL SPRING	<.01	<.01	<.01	<.01	<.1	<1	<.01
106 C L ROBINSON	<.01	<.01	<.01	<.01	<.1	<1	<.01
109 FLOWING SPRING (KANE)	<.01	<.01	<.01	<.01	<.1	<1	<.01
126 RODERICK BROS	<.01	<.01	<.01	<.01	<.1	<1	<.01
139 HARPERS FERRY P S SPRING	<.01	<.01	<.01	<.01	<.1	<1	<.01
156 KENNETH WILT	<.01	<.01	<.01	<.01	<.1	<1	<.01
160 PAUL CHAPMAN	<.01	<.01	<.01	<.01	<.1	<1	<.01
176 HOLLIS-LOWMAN	<.01	<.01	<.01	<.01	<.1	<1	<.01
198 FORREST HAMMOND	<.01	<.01	<.01	<.01	<.1	<1	<.01
232 HARPERS FERRY JOB CORPS	<.01	<.01	<.01	<.01	<.1	<1	<.01
233 WILLIAM JOHNSON	<.01	<.01	<.01	<.01	<.1	<1	<.01
238 FRED DONLEY	<.01	<.01	<.01	<.01	<.1	<1	<.01
239 HS LINK	<.01	<.01	<.01	<.01	<.1	<1	<.01
242 ROBERT TABB	<.01	<.01	<.01	<.01	<.1	<1	<.01
243 ANIMAL WELFARE SOCIETY	<.01	<.01	<.01	<.01	<.1	<1	<.01
244 HOWARD ROPER	<.01	<.01	<.01	<.01	<.1	<1	<.01
245 ALDRIDGE SPRING	<.01	<.01	<.01	<.01	<.1	<1	<.01
245 ALDRIDGE SPRING	<.01	<.01	<.01	<.01	<.1	<1	<.01
245 ALDRIDGE SPRING	<.01	<.01	<.01	<.01	<.1	<1	<.01
245 ALDRIDGE SPRING	<.01	<.01	<.01	<.01	<.1	<1	<.01
247 GLENN JENKINS	<.01	<.01	<.01	<.01	<.1	<1	<.01
249 REBECCA WHIPP	<.01	<.01	<.01	<.01	<.1	<1	<.01
250 STANLEY DUNN	<.01	<.01	<.01	<.01	<.1	<1	<.01
251 CRIM	<.01	<.01	<.01	<.01	<.1	<1	<.01
252 HEAD SPRING	<.01	<.01	<.01	<.01	<.1	<1	<.01
252 HEAD SPRING	<.01	<.01	<.01	<.01	<.1	<1	<.01
252 HEAD SPRING	<.01	<.01	<.01	<.01	<.1	<1	<.01
252 HEAD SPRING	.01	<.01	<.01	<.01	<.1	<1	<.01
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	<.01	<.01	<.01	<.01	<.1	<1	<.01
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	<.01	<.01	<.01	<.01	<.1	<1	<.01
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	<.01	<.01	<.01	<.01	<.1	<1	<.01
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	<.01	<.01	<.01	<.01	<.1	<1	<.01
257 BULLSKIN RUN AT KABLETOWN,WV	<.01	<.01	<.01	<.01	<.1	<1	<.01
257 BULLSKIN RUN AT KABLETOWN,WV	<.01	<.01	<.01	<.01	<.1	<1	<.01
257 BULLSKIN RUN AT KABLETOWN,WV	<.01	<.01	<.01	<.01	<.1	<1	<.01
257 BULLSKIN RUN AT KABLETOWN,WV	<.01	<.01	<.01	.01	<.1	<1	<.01
258 BUTLER WELL	<.01	<.01	<.01	<.01	<.1	<1	<.01
270 LOUTHAN SPRING	<.01	<.01	<.01	<.01	<.1	<1	<.01

Appendix B-6.--Surface-water triazine pesticide analyses

Station name	Latitude	Longitude	Date	Alachlor, total recover (ug/L)	Ametryne, total (ug/L)	Atrazine, total (ug/L)
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	39 11 09 N	077 52 47 W	06-21-89	<0.10	<0.10	0.90
257 BULLSKIN RUN AT KABLETOWN,WV	39 12 57 N	077 51 25 W	06-21-89	<.10	<.10	.60

Station name	Cyanazine, total (ug/L)	Prometone, total (ug/L)	Prometryne, total (ug/L)	Propazine, total (ug/L)	Simazine, total (ug/L)	Simetryne, total (ug/L)	Trifluralin, total recoverable (ug/L)
256 NORTH FORK LONG MARSH RUN NEAR MEYERSTOWN,WV	<0.10	0.1	<0.1	<0.10	0.20	<0.1	<0.10
257 BULLSKIN RUN AT KABLETOWN,WV	.10	.1	<.1	<.10	.20	<.1	<.10

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